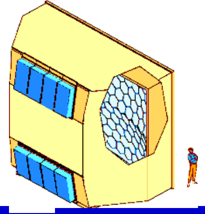


THGEM experience with COMPASS

(first use of THGEMs in a running experiment)

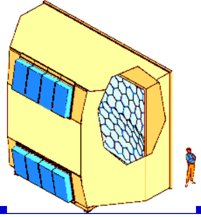
S. Dalla Torre

On behalf of the

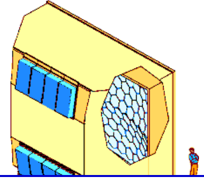
TRIESTE COMPASS RICH GROUP

(also involved in the project:

Alessandria, Aveiro, Freiburg, Liberec, Prague, Torino, Munich-TUM, Sacaly)



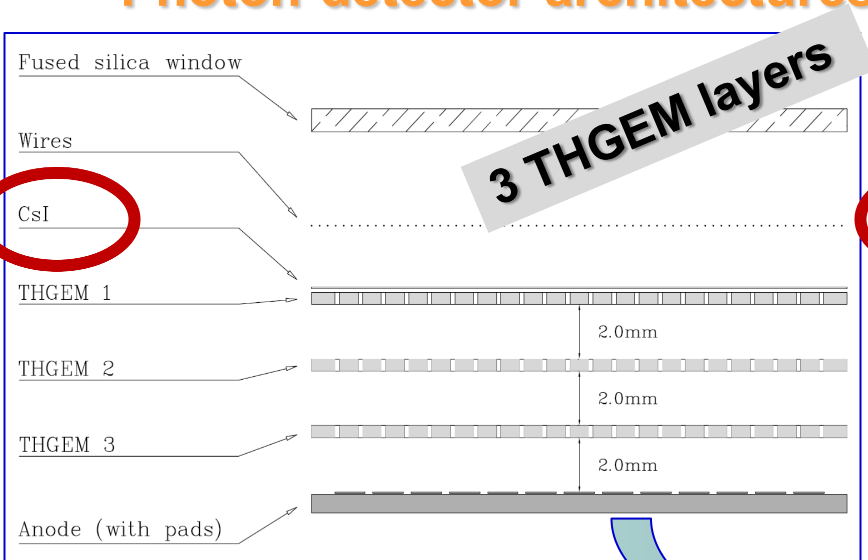
INTRODUCTION

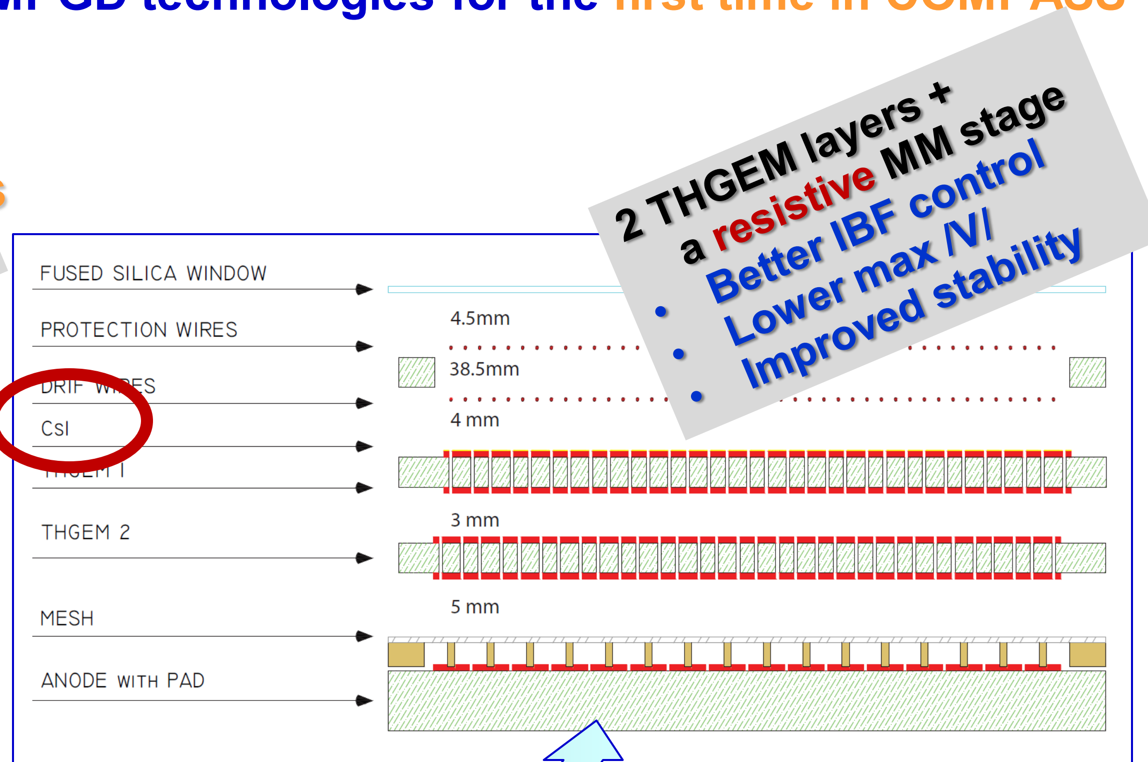


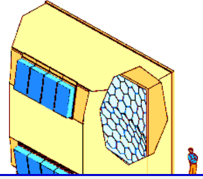
GOAL

- **MPGD-based single photon detectors for COMPASS RICH**
  - **Starting from MWPCs with CsI photocathodes (RD26, our direct experience for COMPASS RICH)**
  - **MPGD to control ion back flow and photon feedback (ageing, instabilities)**
  - **MPGD to have intrinsically fast detectors (rate capabilities)**
  - **Single photon detectors by MPGD technologies for the first time in COMPASS RICH**

- **Photon detector architectures**



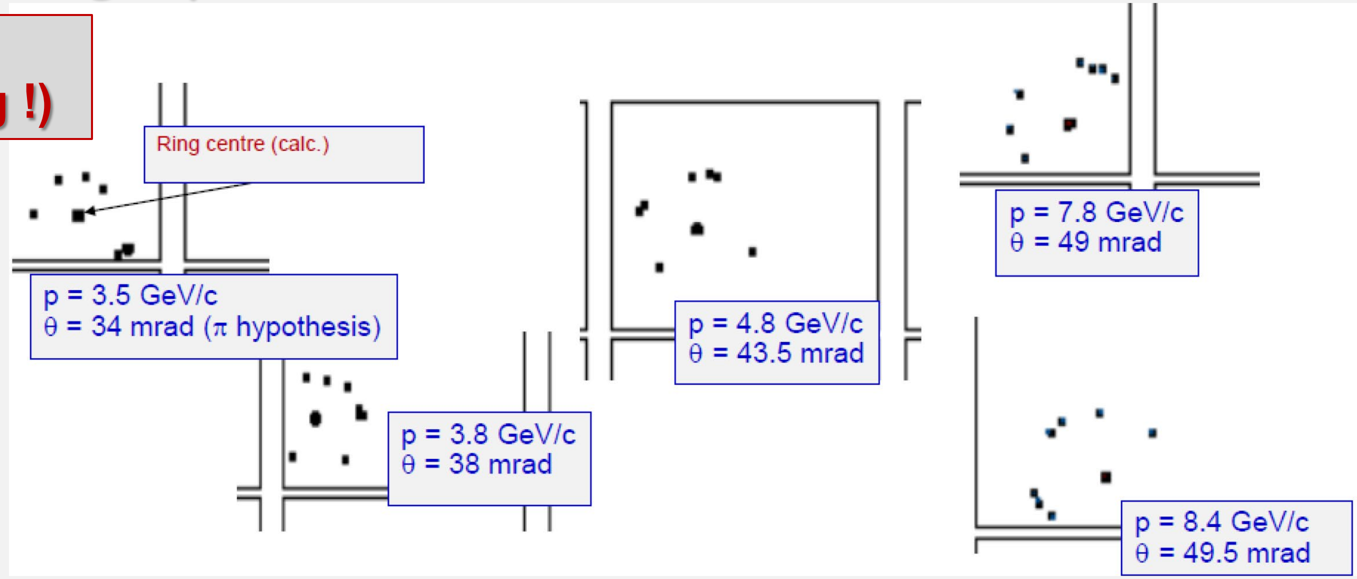




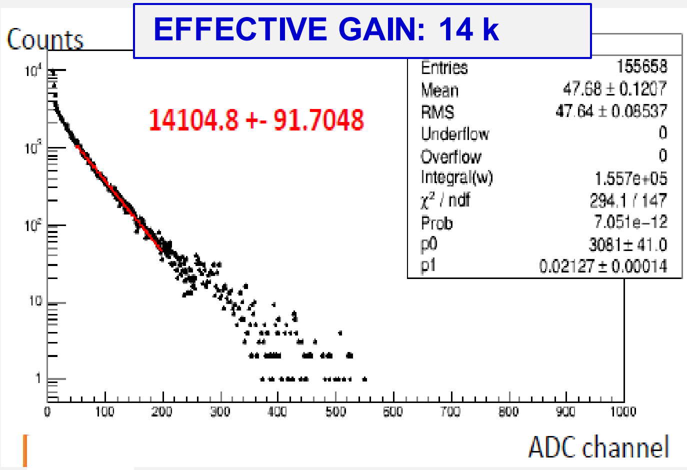
PERFORMANCE OF THE HYBRID MPGD

The novel gaseous single photon detectors of COMPASS RICH

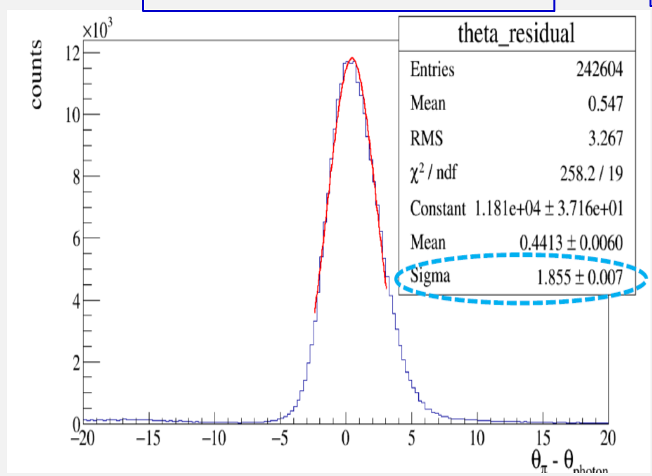
EVENT DISPLAY (no image filtering !)



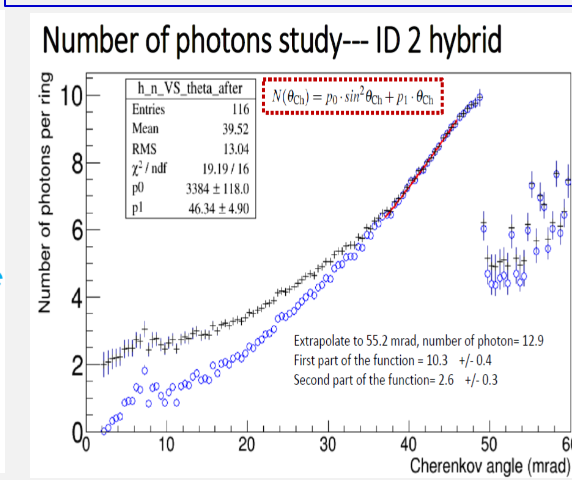
EFFECTIVE GAIN: 14 k

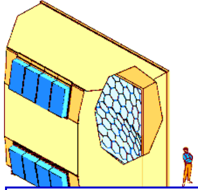


Resolution: 1.8 mrad



n. of photons/ring : 10-12 (β → 1)

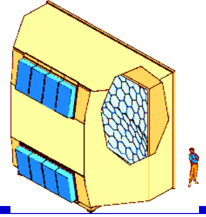




ACHIEVEMENTS

- **MPGD-based photon detectors ACCOMPLISH THEIR MISSION in COMPASS RICH**
  - **stable gain and large gain**
  - **fine resolution**
  - **good number of detected photoelectrons**

- **Technological achievement - for the FIRST TIME:**
  - **single photon detection is accomplished by MPGDs in an experiment**
  - **THGEMs used in an experiment**
  - **resistive MM used in an experiment**
  - **MPGD gain > 10k in an experiment**
  - **gain stable at 6% level over months**



THE PHASES of the THGEM ACTIVITY

- 7 years of R&D
  - Deep understanding of THGEM with reference to the single photon detection

- Mass production, quality control and out come

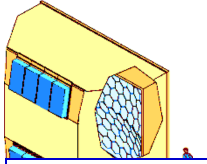
NOTES: material organized in logic order

(not present according to a chronological sequence);

highlights of interest here

(the whole exercise includes much more)

METHODS & INSTRUMENTS WE USED

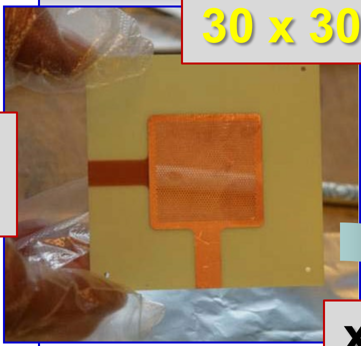


OUR STUDIES, WHAT AND HOW

- **Characterisation of small size (30 x 30 mm^2) THGEM prototypes**
  - Single layer arrangement
  - Multiple layer arrangement
  - Using X-ray sources
  - Using UV light sources
  - Cherenkov light at the test beams
  - Analog read-out, single channel
  - Digital read-out, 1 channel per anode pad
  - Read-out of the current on the various electrodes
- **Towards large sizes**
  - INTERMEDIATE STEP: 300 x 300 mm^2 prototypes and test of detector of this size
    - Economical and practical considerations
    - Engineering development possible with this size
  - FINAL SIZE: 600 x 300 mm^2 prototypes → production

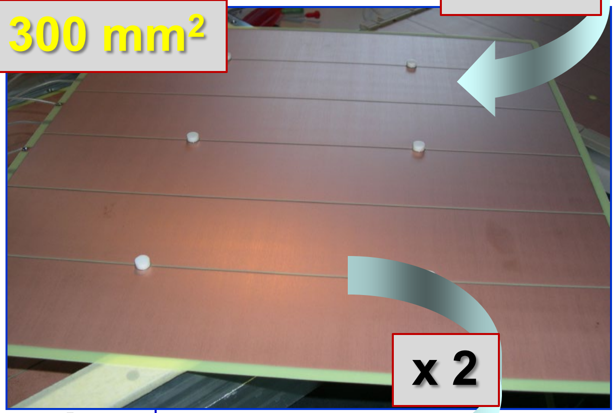
~50 different THGEM samples studied

30 x 30 mm^2

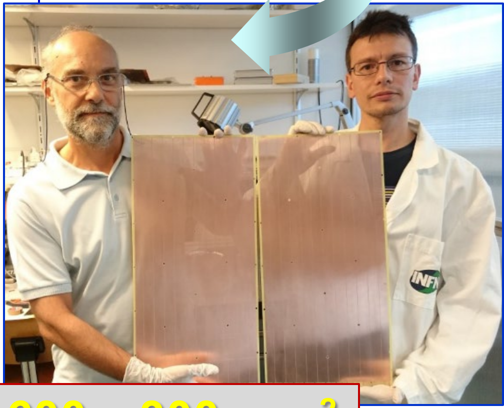


x 100

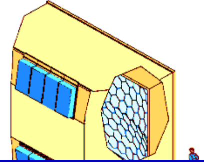
300 x 300 mm^2



x 2



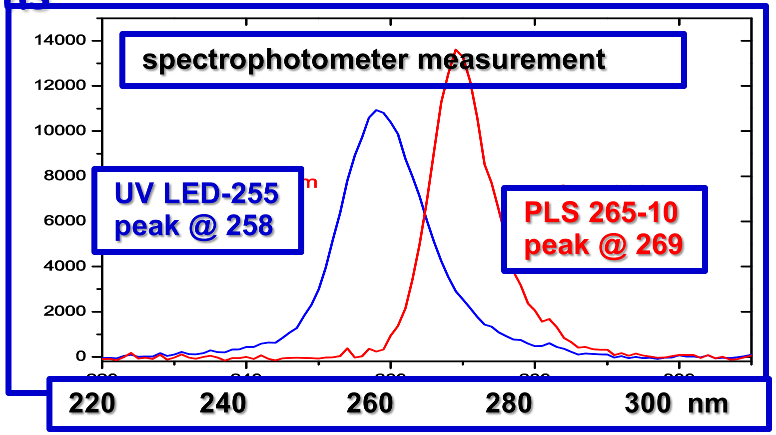
600 x 300 mm^2



LIGHT SOURCES

1. **UV- LEDs** also called germicidal ray (disinfection)

- **The first one used: Model UV LED-255**
  by Seoul Optodevice Co., Ltd, Seoul, Korea (South)
- **Central wavelength: 255 ± 10 nm**
- **Reverse bias: pulse width a few x 10 ns**



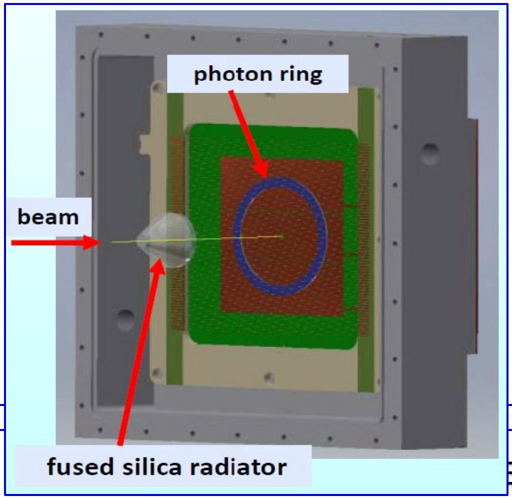
2. **PLS 265-10 (pulsed LED) and controller**

   by PicoQuant GmbH, Berlin, Germany

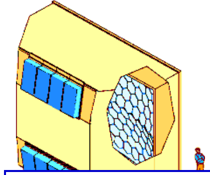
- **600 ps long pulses**
- **up to 40 MHz**

3. **At test beams:**

   Cherenkov light (CsI is a must)

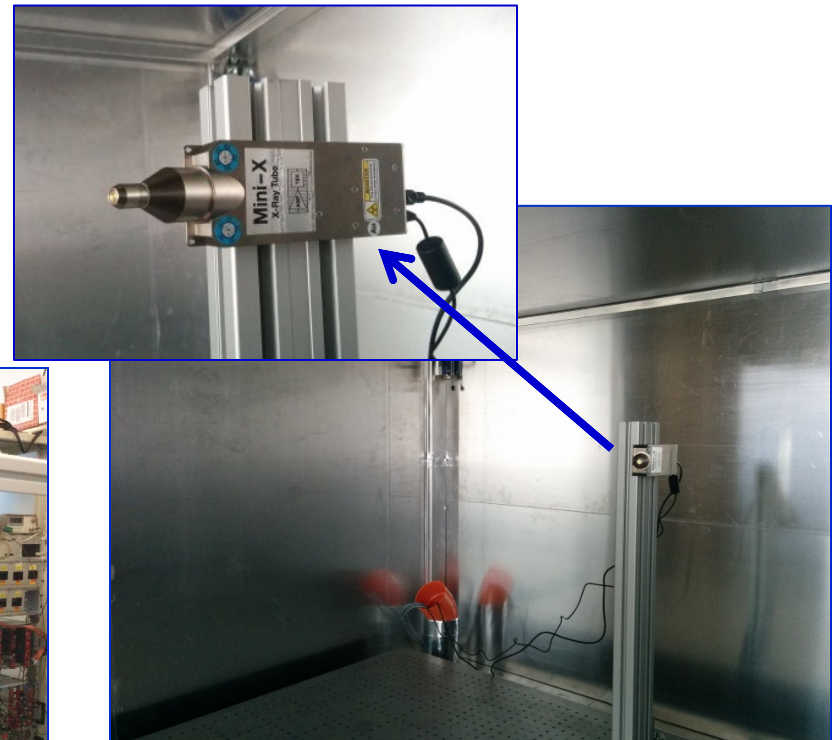


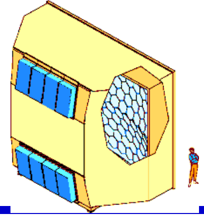
TUNING THE LIGHT INTENSITY
SINGLE PHOTOELECTRON MODE
From metallic surfaces



X-RAYs

- Standard ^{55}Fe sources
- Mini X-gun (Amptex, 10 KeV) station (used for quality control)





READ-OUT CHAINS

R&D

EXPERIMENT

Analog, single ch.

1)

- ORTEC preamplifier model 142
- ORTEC amplifier model 450
- Analog Digital Converter (ADC) LeCroy model 2259

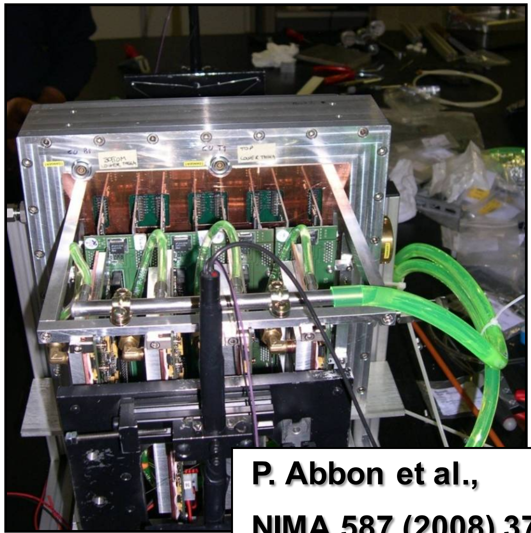
2)

- CREMAT CR-111 charge sensitive preamplifier
- a CREMAT CR-200 shaping amplifier
- MultiChannel Analyser (MCA) model 800A by Amptek

Digital, multich.

- FE: C-MAD chip
  - min thr. 2 fC
- F1 TDC
  - resolution: 108 ps

(used for COMPASS RICH MAPMTs)

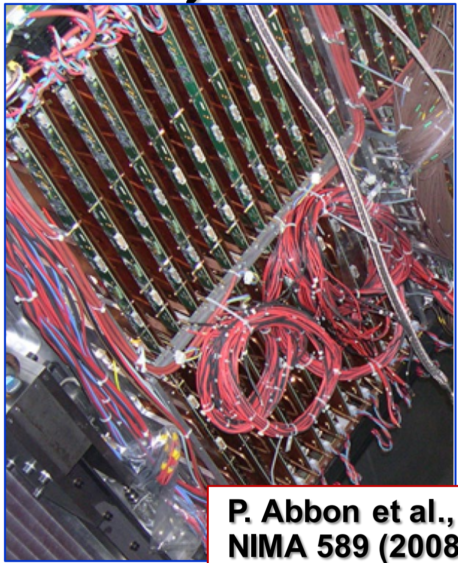


P. Abbon et al., NIMA 587 (2008) 371

Analog, multich.

- FE: APV-25 chip
- Noise coupled to the hybrid MPGD photon detectors: 900 e-)

(used for COMPASS RICH MWPCs)



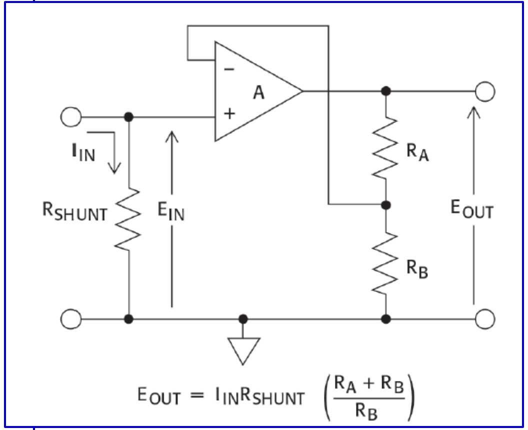
P. Abbon et al., NIMA 589 (2008) 362

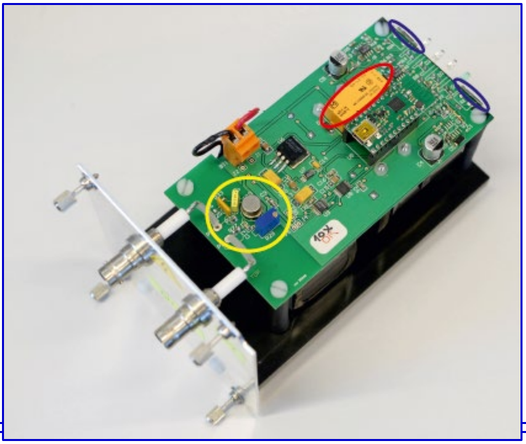
Picoammeters

1) **Commercial, 1 ch.**
   - Keithley 6517A (current res. down to 0.1 pA)

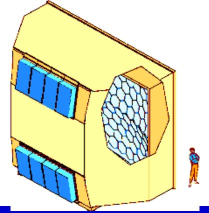
2) **Home-made, battery powered (fully floating)**

- a current-voltage converter, based on an operational amplifier with very low input current, a high precision ADC
  - a radio controlled data acquisition unit and the computer-based control, visualization and storage
  - Precision **~0.1 pA, current ΔV up to 8 kV**



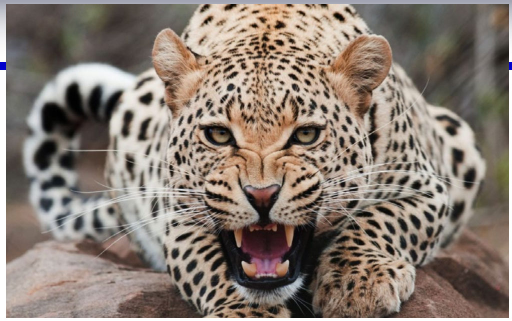


M. Bari et al., PoS (MPGD2017) 068

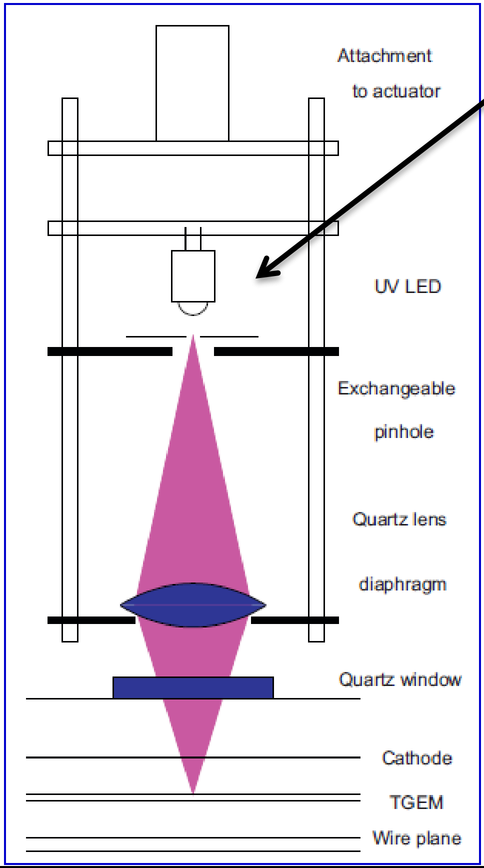


HIGH RESOLUTION GAIN & EFFICIENCY MAPS

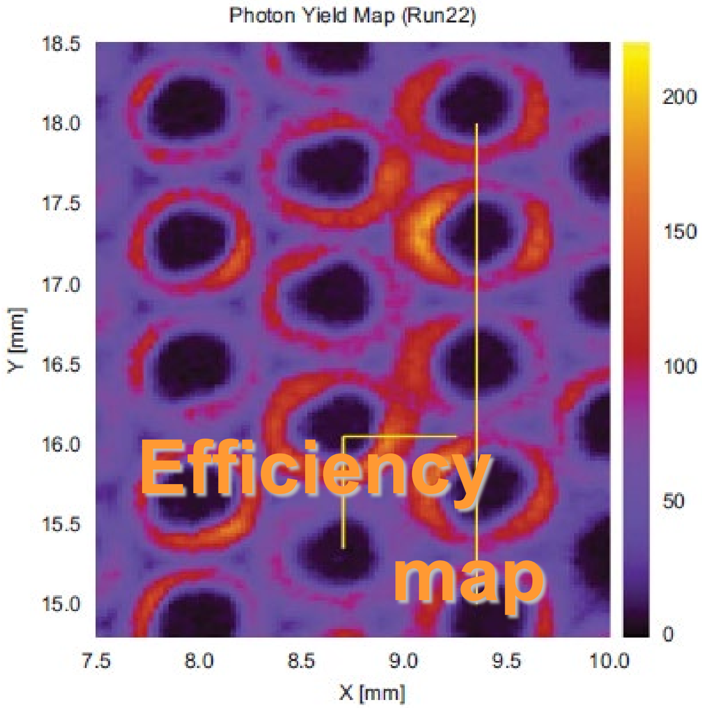
THE LEOPARD

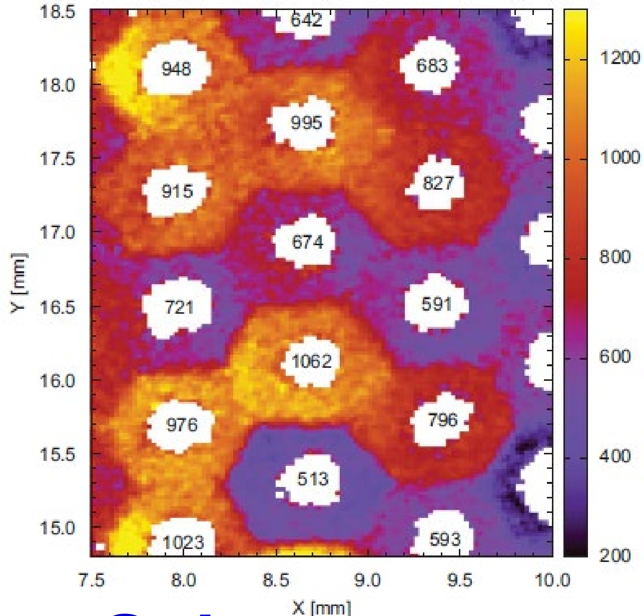


- **hole by hole GAIN maps**
- **fine step (~ 100 μm) EFFICIENCY maps**



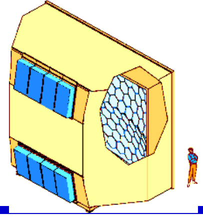
Light source and optics on a moving table





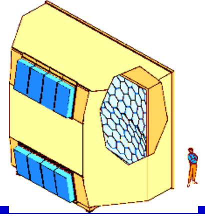
Gain map

G.Hamar and D. Varga, NIMA 694(2012)16

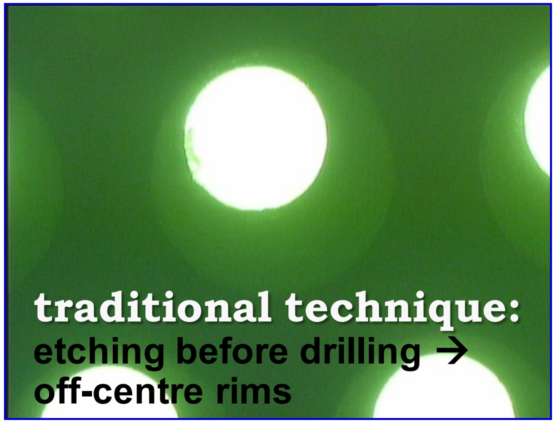


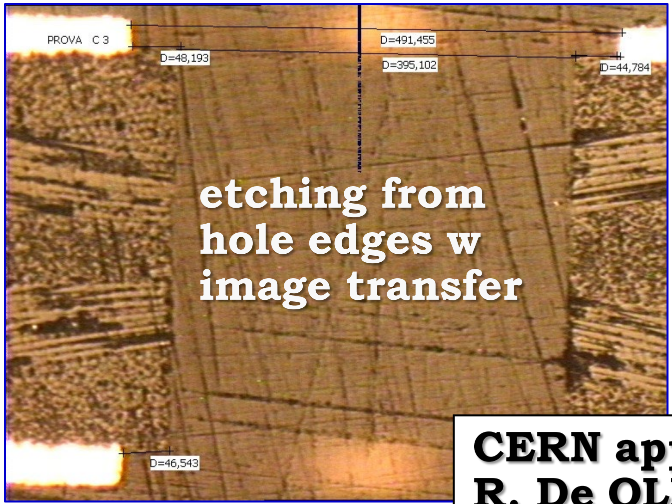
THGEM

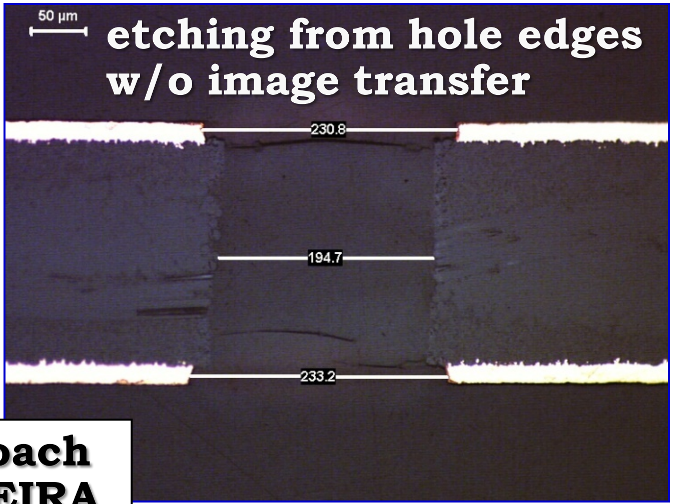
MUNUFACTUTING



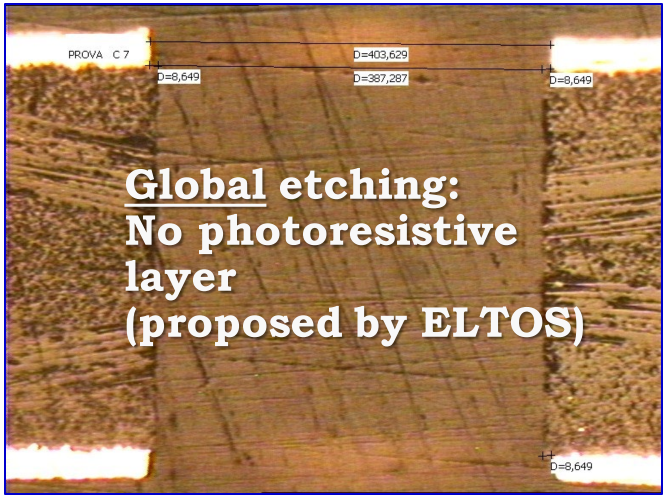
THGEM PRODUCTION

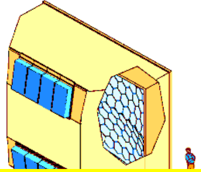






CERN approach
R. De OLIVEIRA

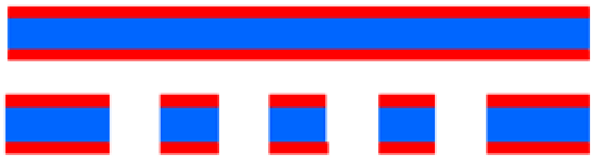




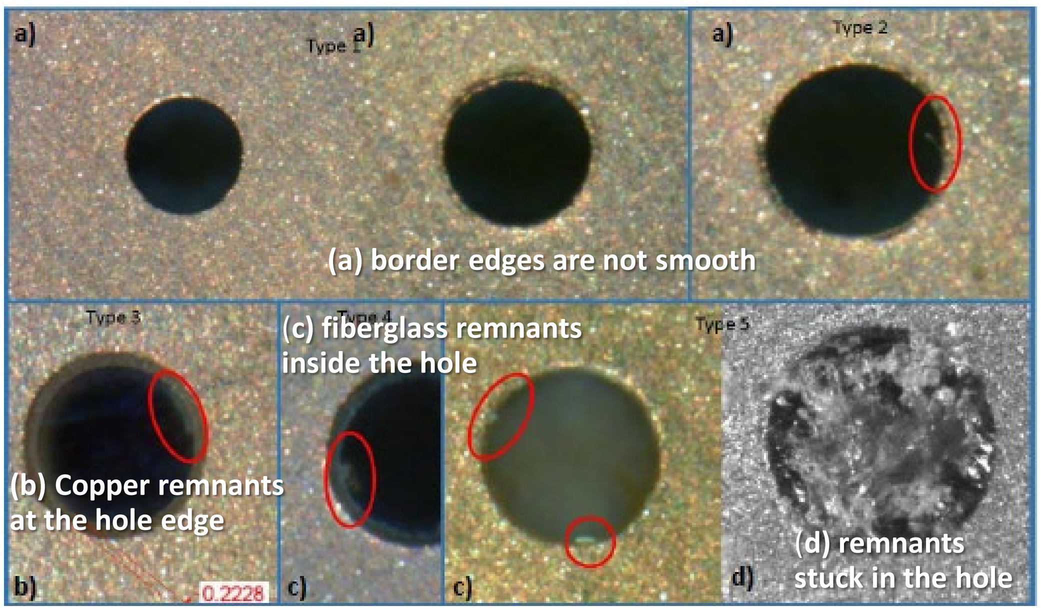
THGEM PRODUCTION

our choice (for "no rim" THGEMs)

industrial phase: only drilling, followed by a finishing protocol

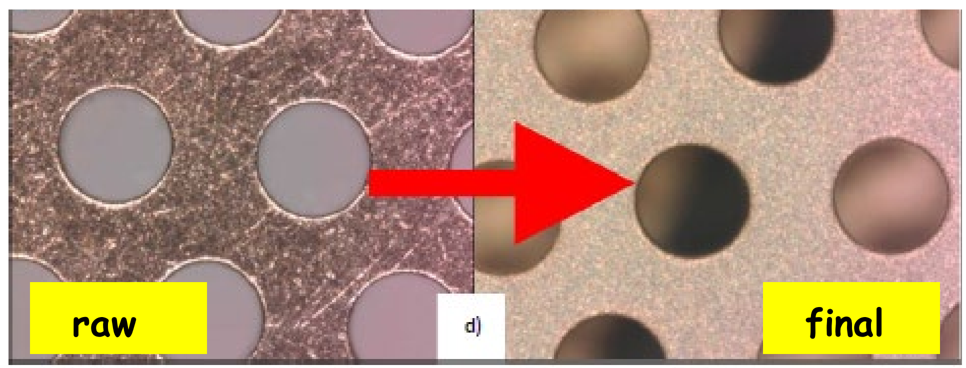


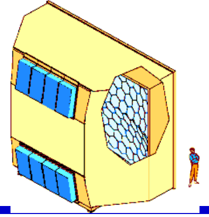
after drilling



FINISHING PROTOCOL

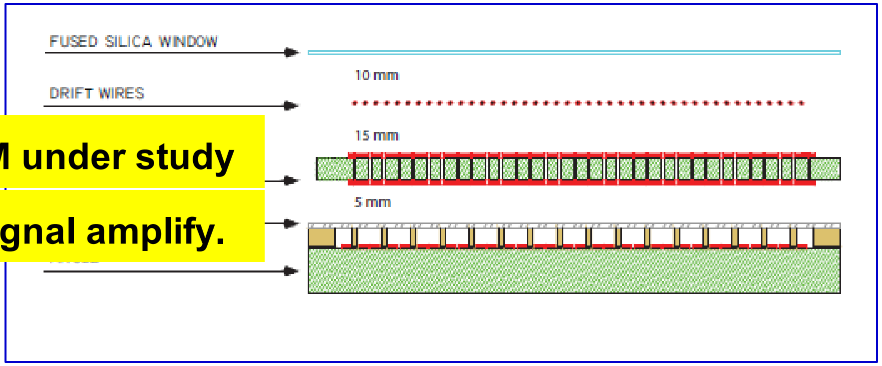
- **polishing** the surfaces by orbital grinding machine using **fine grain pumice powder** (60-100 μm);
- removing remnants from the surface and by **high pressurized water**;
- smoothing the THGEM surface and hole edges by an **ultrasonic bath with high PH solution** (SONICA PCB Cleaner4, PH: 11) at 60^{o}C temperature for two hours;
- rinsing with distillated water;
- **drying and complete fiberglass polymerization** in oven at 120^{o}C for 24 h





THGEM QUALITY

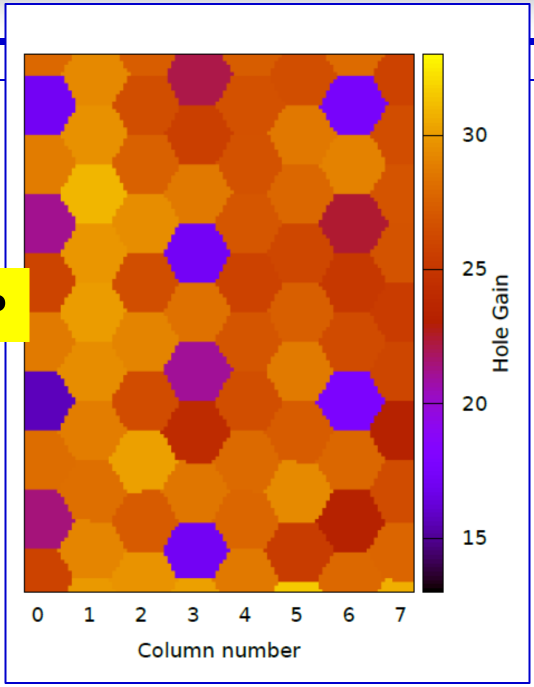
"hole by hole" studied using the LEOPARD



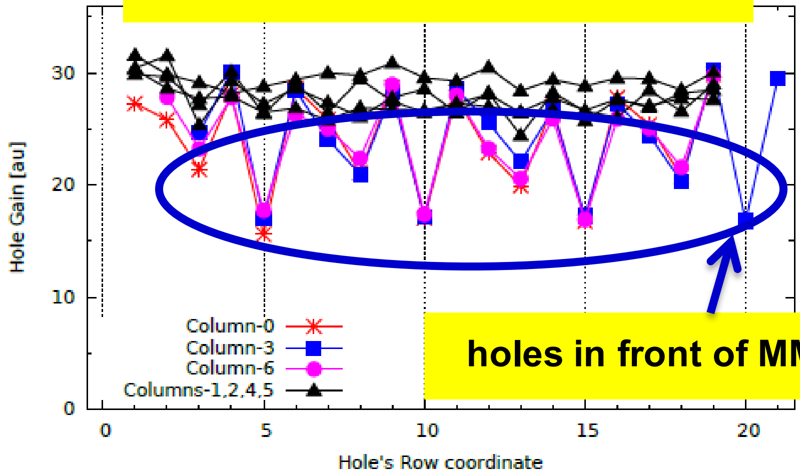
THGEM under study

MM for signal amplify.

GAIN MAP

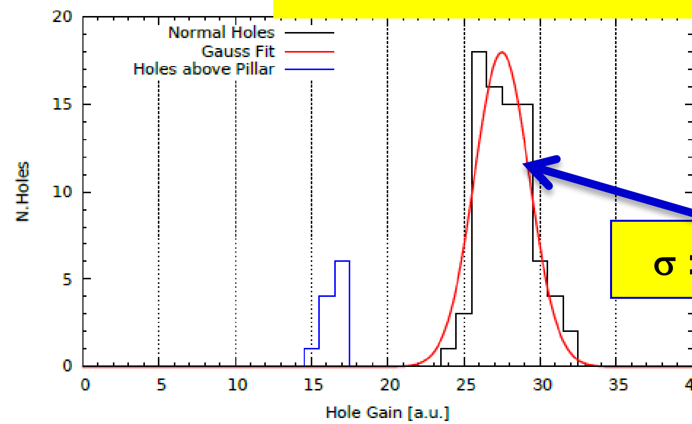


GAIN vs row (for each column)

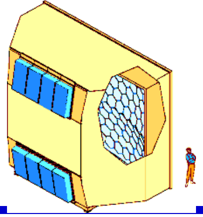


holes in front of MM pillars

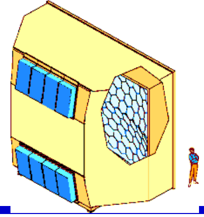
GAIN DISTRIBUTION



σ : 6.5 %



THGEM GEOMETRY

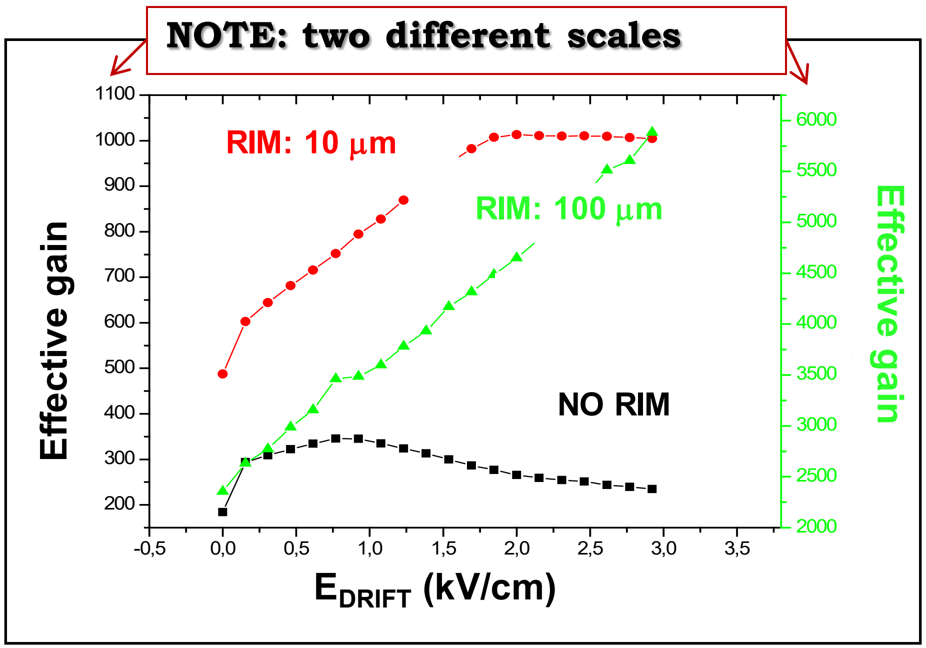


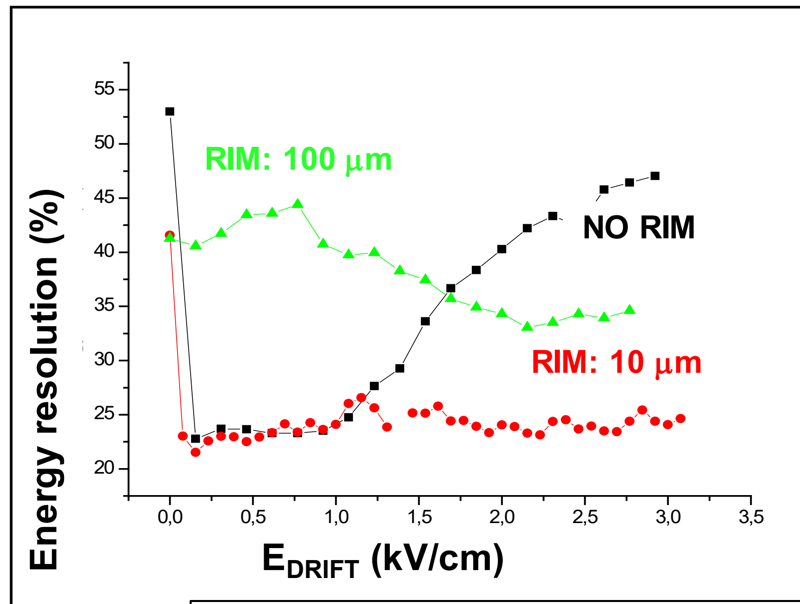
UNDERSTANDING THE RIM

X-ray measurements

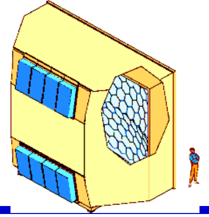
DRIFT SCAN

the optimal drift filed guides the ionization electrons into the holes





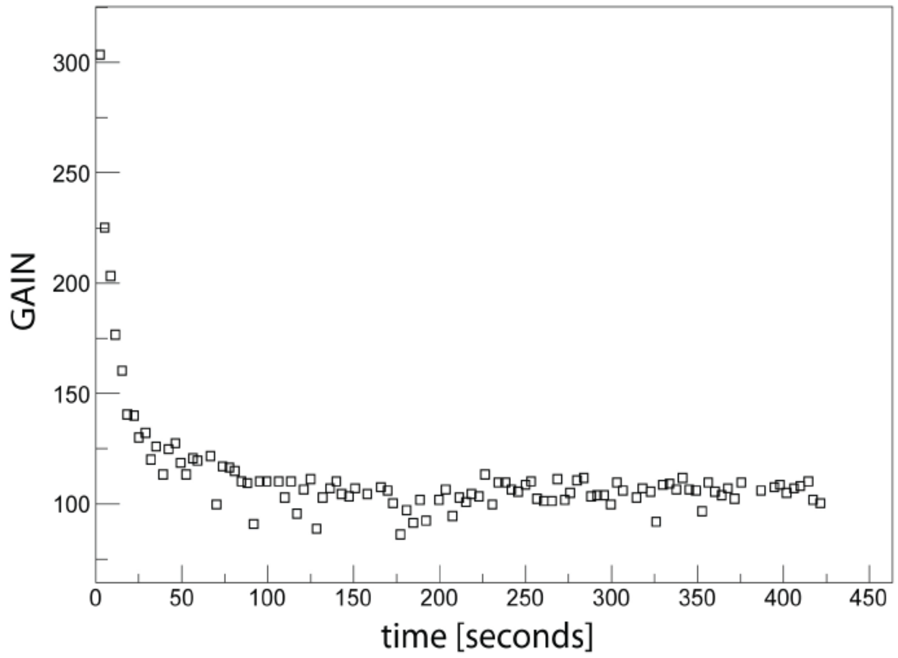
S. Dalla Torre et al.,
IEEE – NSS 2008 , Dresden 19-25/10/2008



GAIN TIME EVOLUTION

1. Fast evolution (~ 1'-20')

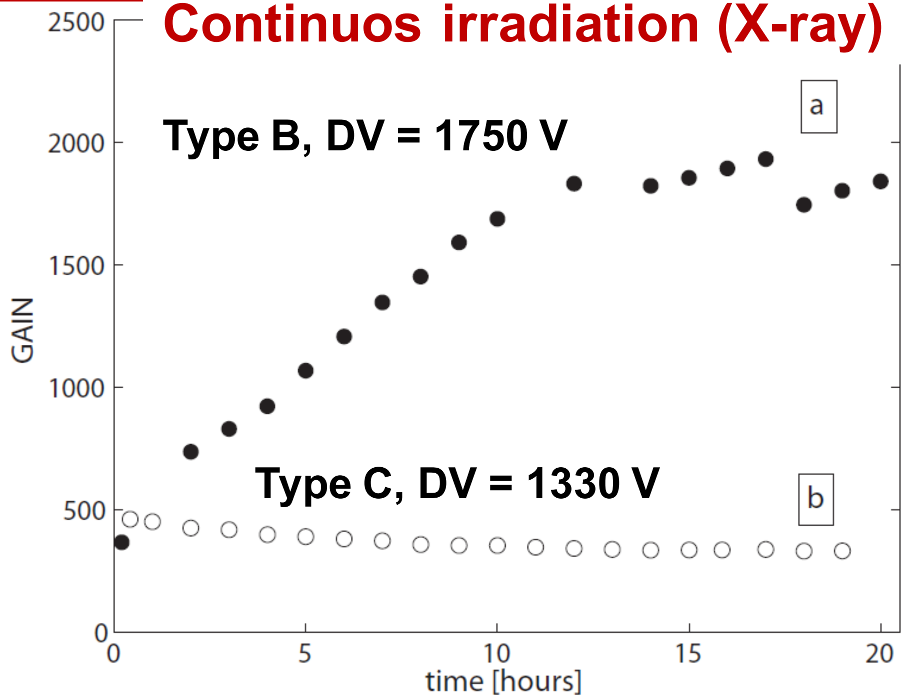
THGEM geometry: type	pitch mm	diameter mm	thickness mm	rim annulus width μm
A	0.2	0.4	0.2	40

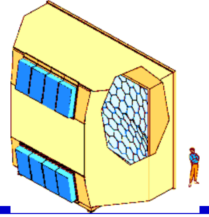


2. Long-term time-evolution

THGEM geometry: type	pitch mm	diameter mm	thickness mm	rim annulus width μm
B	0.8	0.4	0.4	100
C	0.8	0.4	0.4	0

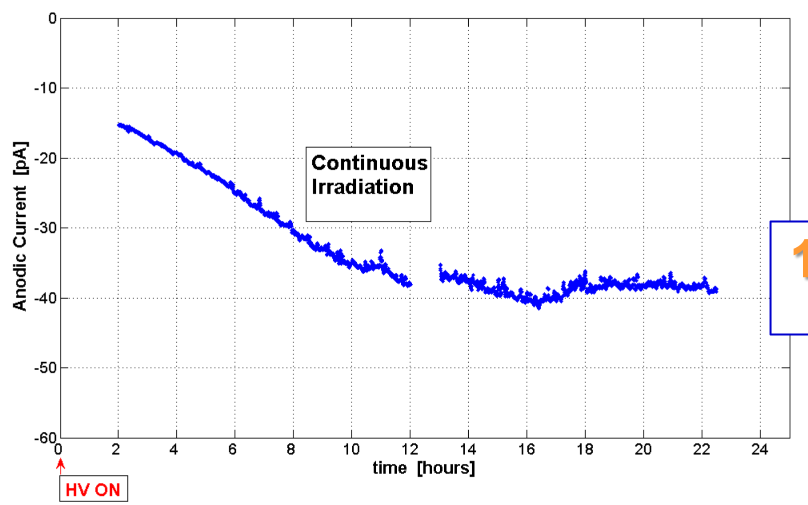
Continuos irradiation (X-ray)

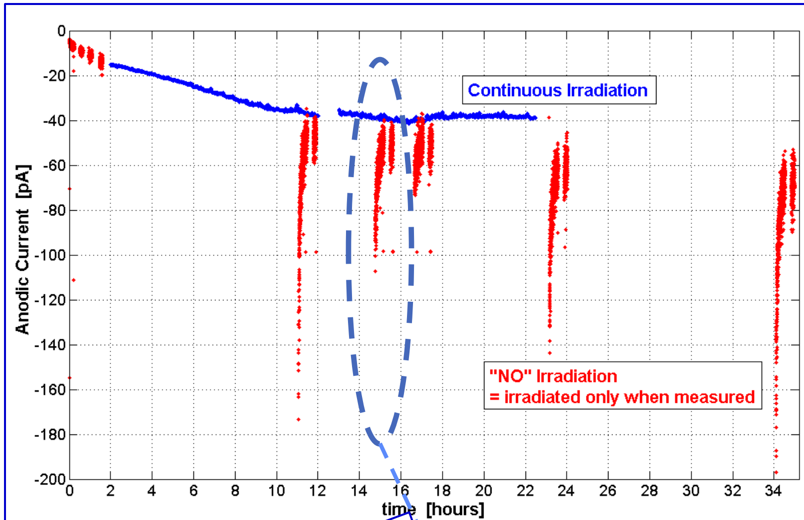




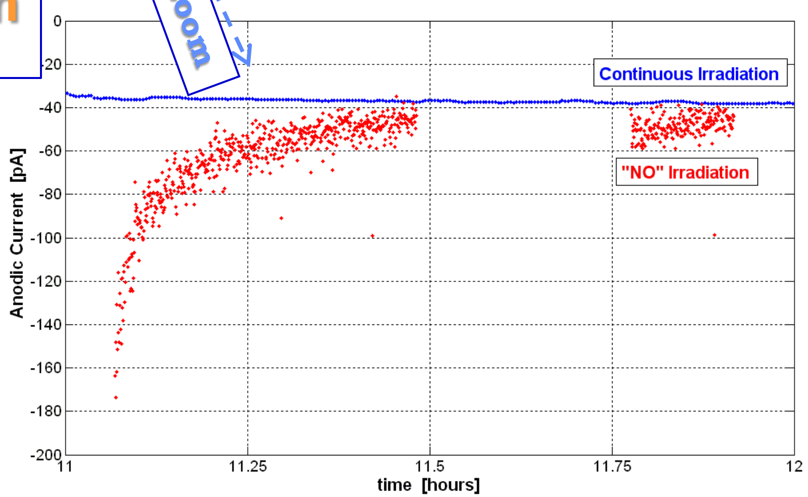
THE ROLE OF THE RIM

Long term studies measuring currents

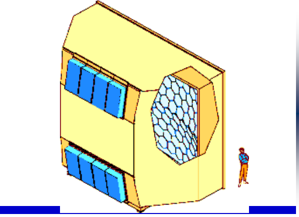




100 μm rim



M. Alexeev et al.,
JINST 10 (2015) P03026



LONG TERM GAIN EVOLUTION

- **A SLOW movement of ions in the PCB fibreglass when power is applied (not dielectric polarization)**
- **EFFECTS:**

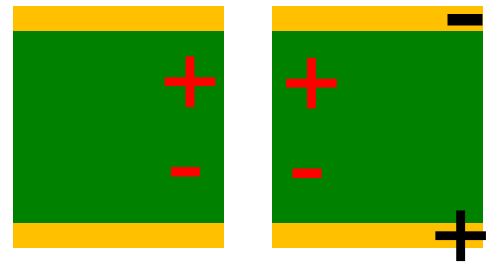
i. The field inside a THGEM hole is modified due to the presence of a net charge distribution along the cylindrical hole wall

ii. at the PCB faces, charge migration from the uncoated rim region toward the metallized area takes place

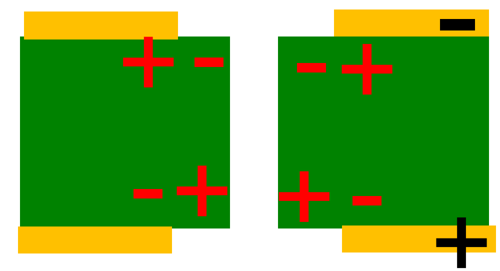
  - **REMARK:** the charge accumulation is screened in the metallized region, not at the uncoated rim annulus and along the hole wall

- no rim or small rim THGEMS: the charge distribution due to (i) generates an electric field opposite to bias one, while effect (ii) is absent or non dominant → gain decreases versus time
- large rim THGEMS: the net charge at the rim surface due to effect (ii) reinforces the bias electric field → gain increases vs time
  - When the detector is irradiated, the accumulated charge distribution partially compensates this gain

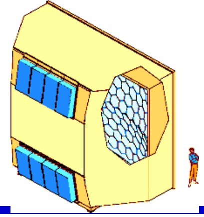
i.



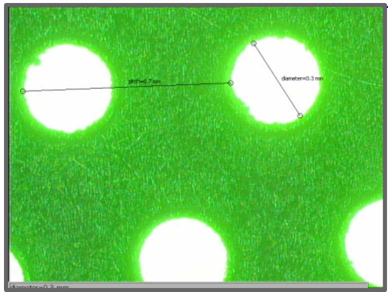
ii.



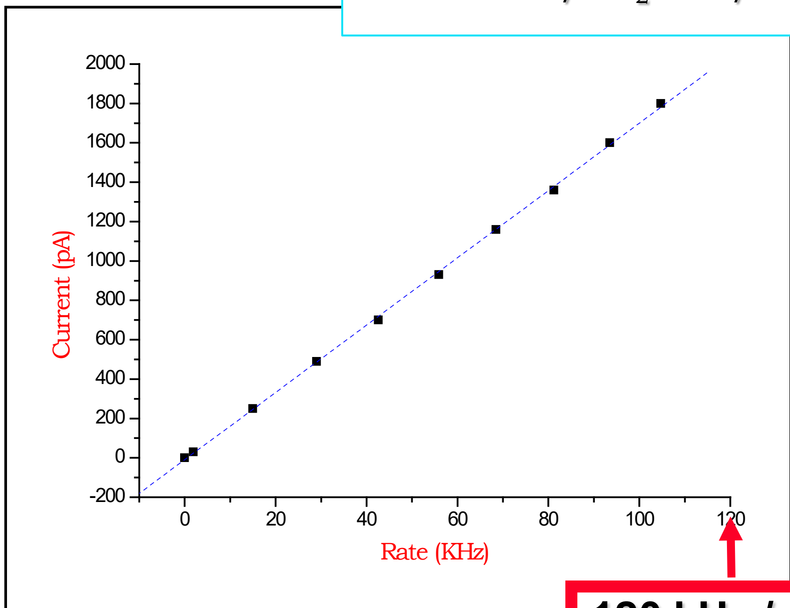
M. Alexeev et al., JINST 10 (2015) P03026



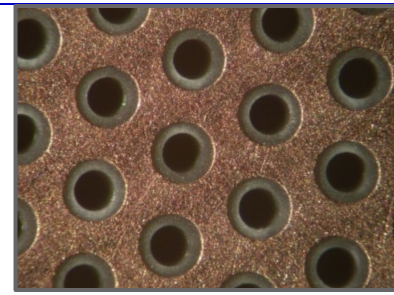
RIM & RATES



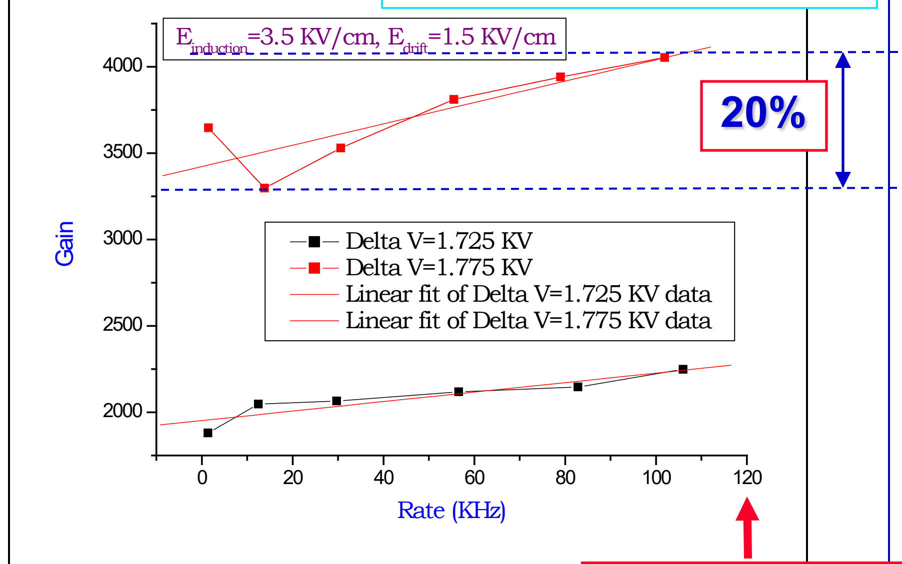
PARAMETERS:
- Diameter = 0.3 mm
- Pitch= 0.7 mm
- Thickness = 0.4 mm
- Rim = 0 mm
- Gas: Ar/CO_2 = 70/30



120 kHz / mm²



PARAMETERS:
- Diameter = 0.3 mm
- Pitch= 0.7 mm
- Thickness = 0.4 mm
- Rim = 0.1 mm
- Gas: Ar/CO_2 = 70/30



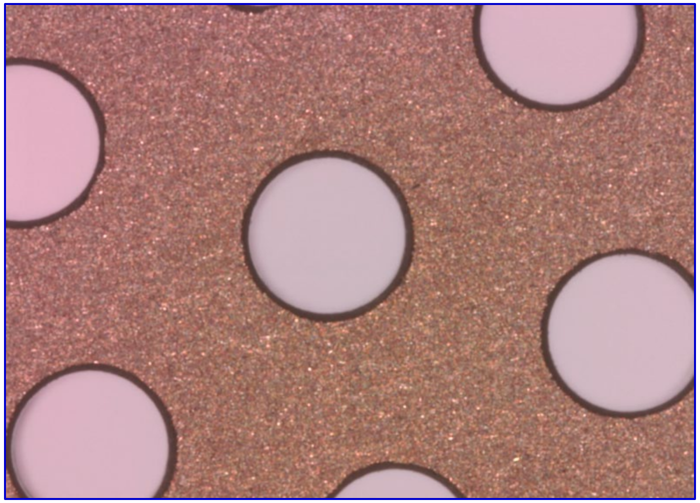
120 kHz / mm²

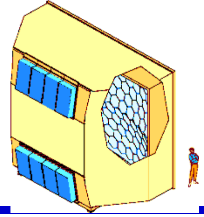
RECALL:
120 kHz/ mm², 300 e- → single photoelectron rates of ~35 MHz/ mm²

RIM, OUR CHOICE

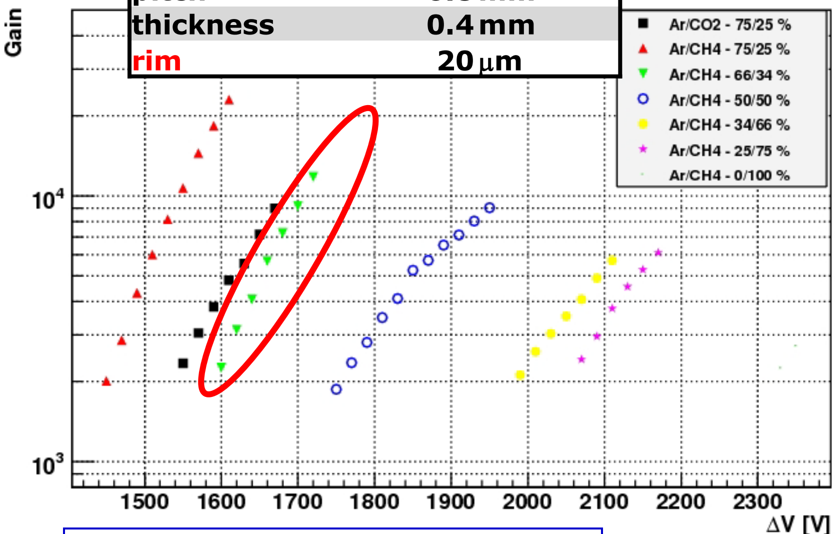
OUR CHOICE:

~ no RIM, i.e. the minimum formed by micro-etching needed to smoth the metalic edges of the holes



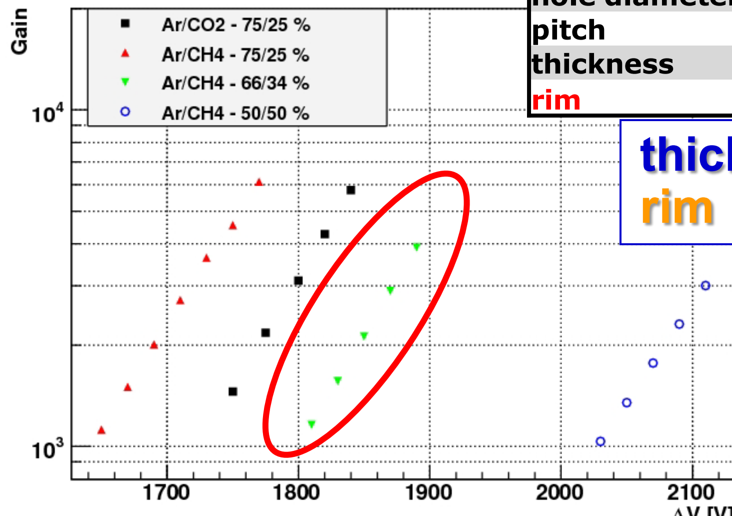


THGEM GAIN & THICKNESS



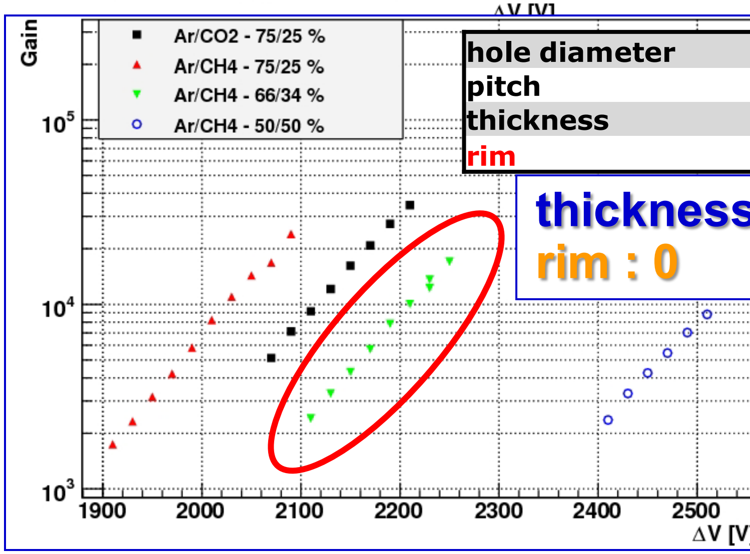
hole diameter	0.4	mm
pitch	0.8	mm
thickness	0.4	mm
rim	20	µm

thickness: 0.4 mm
rim : 20 µm



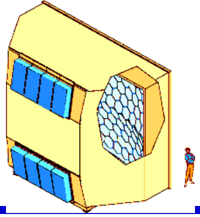
hole diameter	0.4	mm
pitch	0.8	mm
thickness	0.6	mm
rim	0	

thickness: 0.6 mm
rim : 0

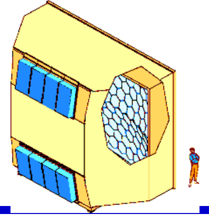


hole diameter	0.4	mm
pitch	0.8	mm
thickness	0.8	mm
rim	0	

thickness: 0.8 mm
rim : 0

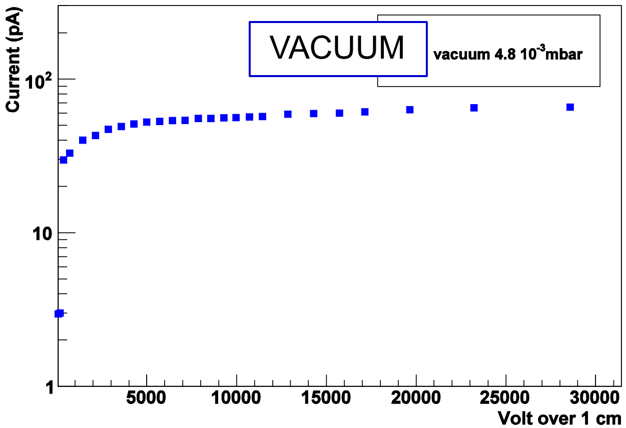


PHOTOELECTRON EXTRACTION & COLLECTION

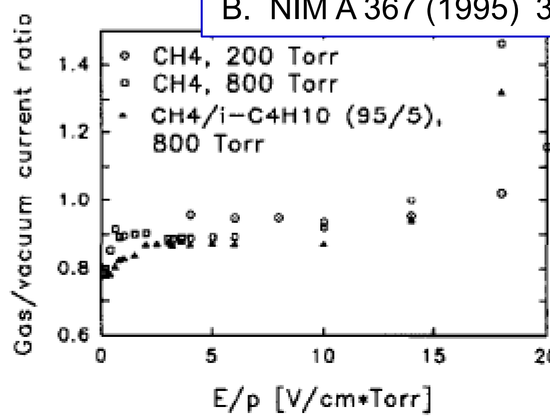


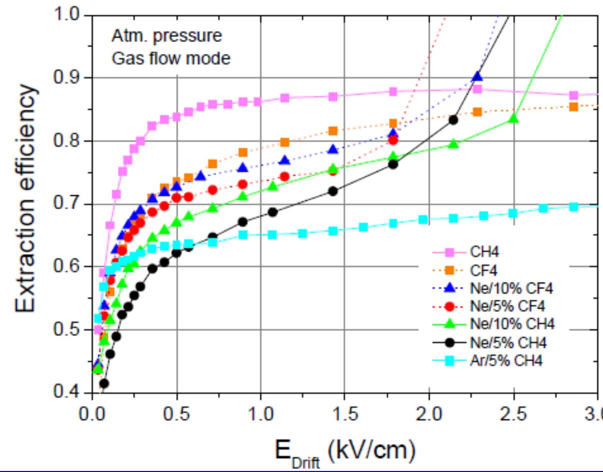
THE ISSUE 1/2

▪ Photoelectron extraction from a CsI film, the role of gas and E

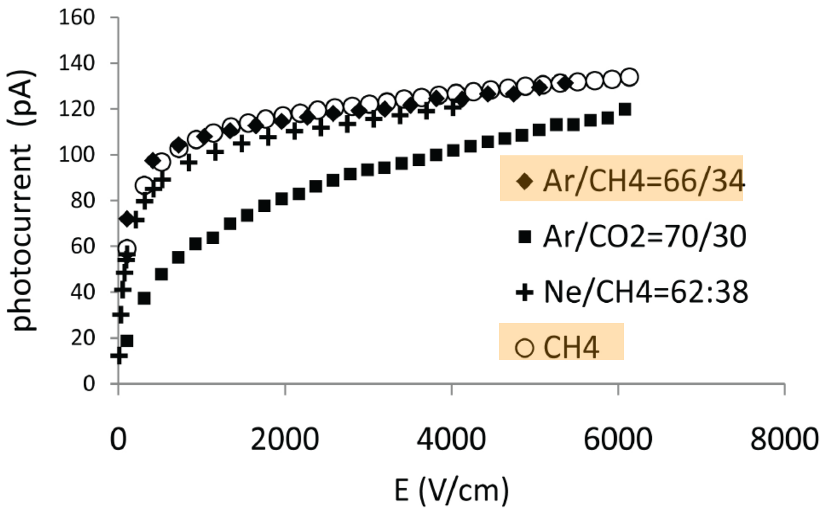


A. Breskin et al.,
B. NIM A 367 (1995) 342

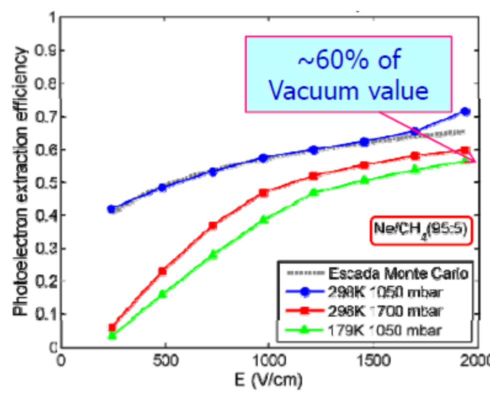


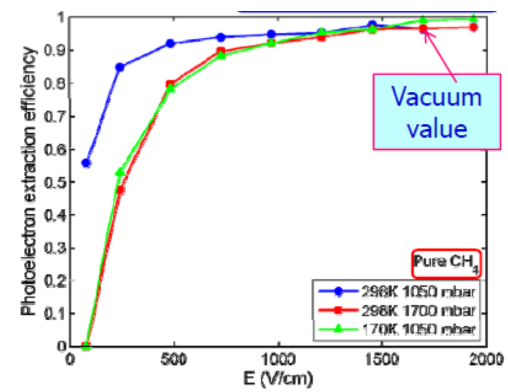


C. D. R. Azevedo et al., 2010 *JINST* 5 P01002



M. Alexeev et al., NIM A 623 (2010) 129





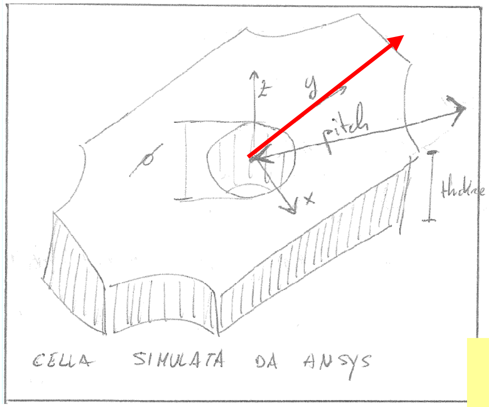
Ne-mixtures ➔ lower operation HV but lower efficiency (~60% of vacuum value)
CH_4 ➔ high operation HV, but high extraction efficiency (close to vacuum)
Other gases investigated

NDIP 2011 – Samuel Duval

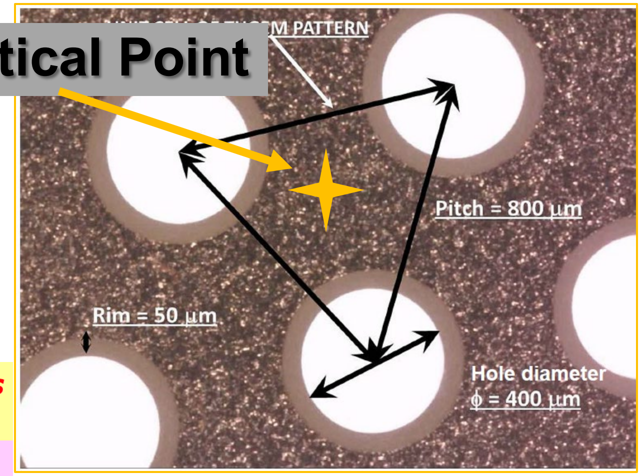
DIPOLE FIELD,

No drift field consider here, approaches by electrostatic calculations

Basic cell structure



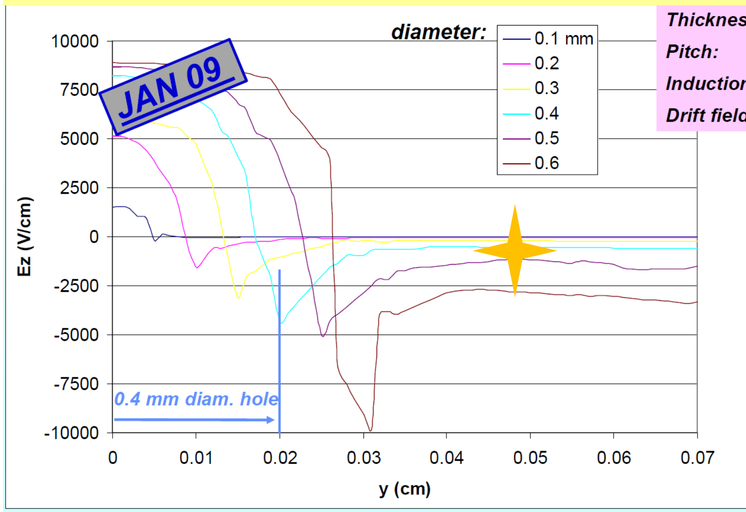
Critical Point



ΔV: 1500 V

Values of E_z along the "y" axis, for different diameters

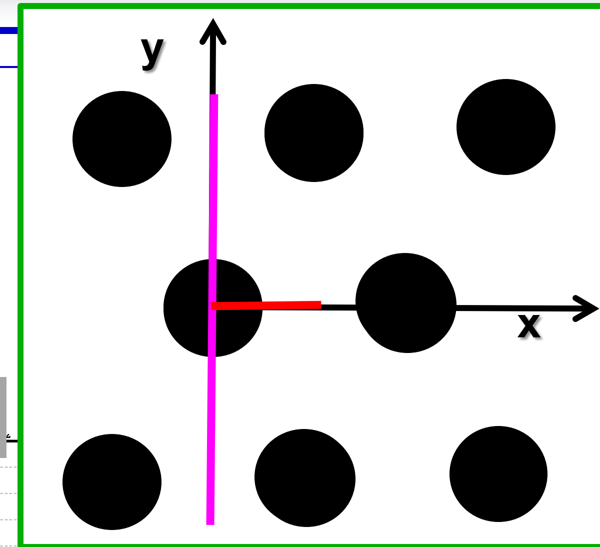
Thickness: 0.6 mm,
Pitch: 0.8 mm,
Induction field: 0.0 V/cm
Drift field: 0.0 V/cm

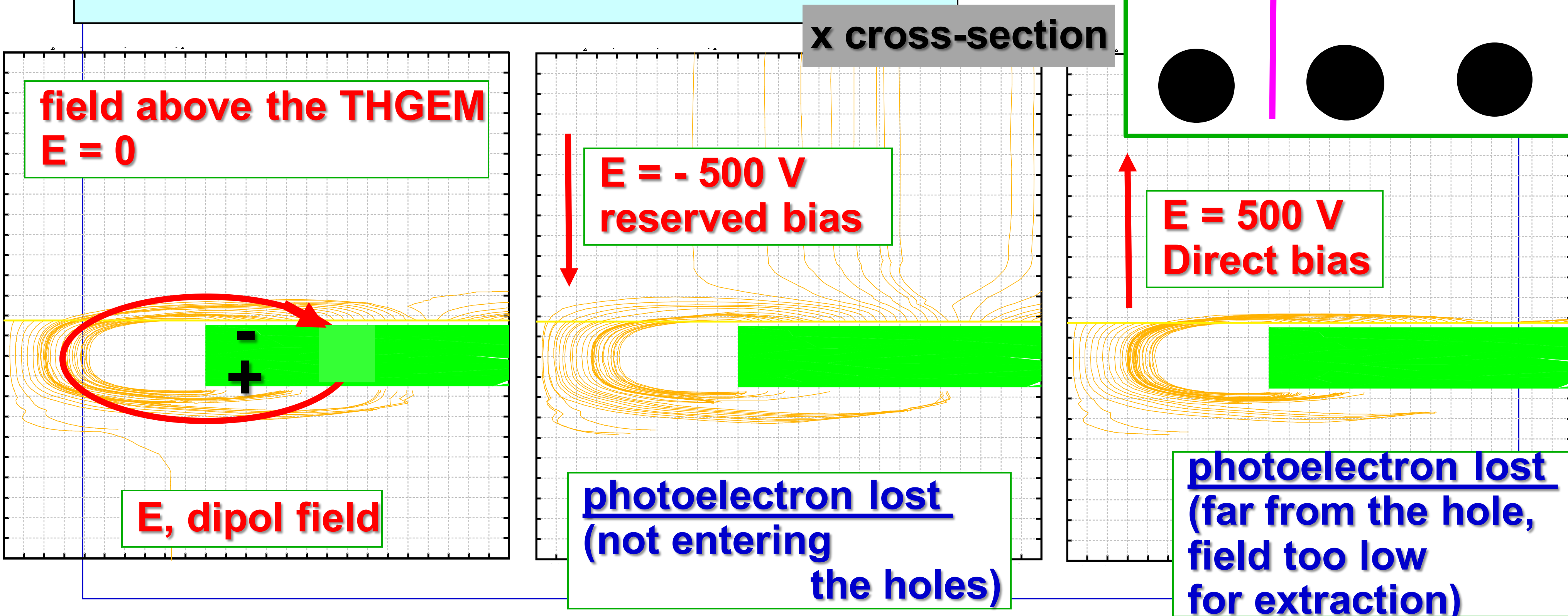


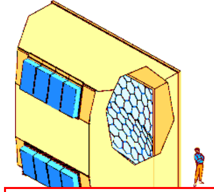
SIMULATING ELECTRON TRAJECTORIES

photoelectron trajectories from a THGEM photocathode, simulation, multiplication switched off

thickness 0.6 mm, diam. 0.4 mm, pitch: 0.8 mm, ΔV = 1500 V

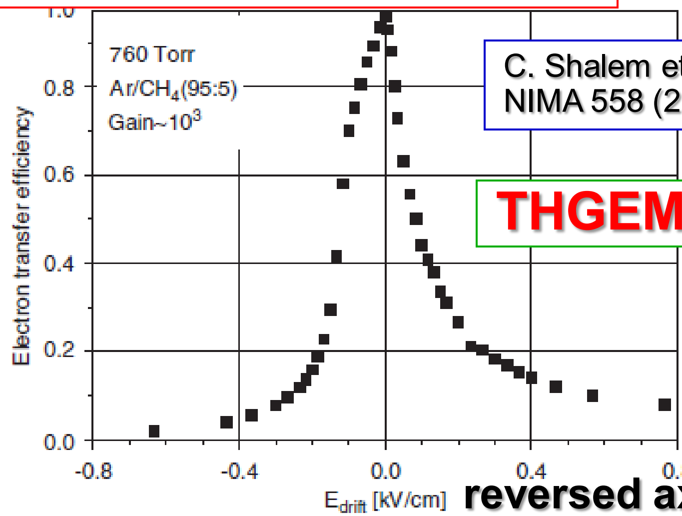






PRELIMINARY MEASUREMENTS

Counting mode technique

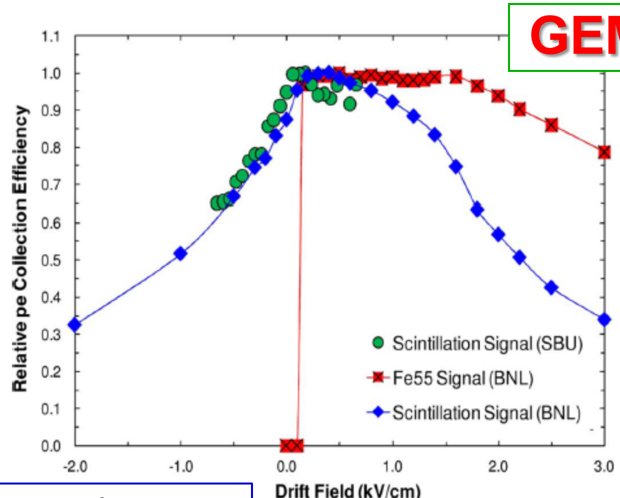


C. Shalem et al., NIMA 558 (2006) 475

THGEMs

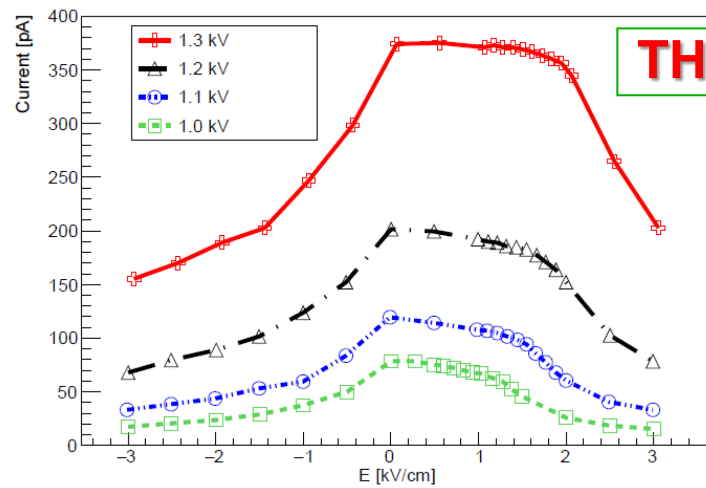
reversed axis

GEMs



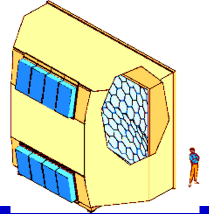
B. Azmoun et al., IEEE TNS, (2009) 1544

Measuring anode current, **combined effect of gain and extraction efficiency**



THGEMs

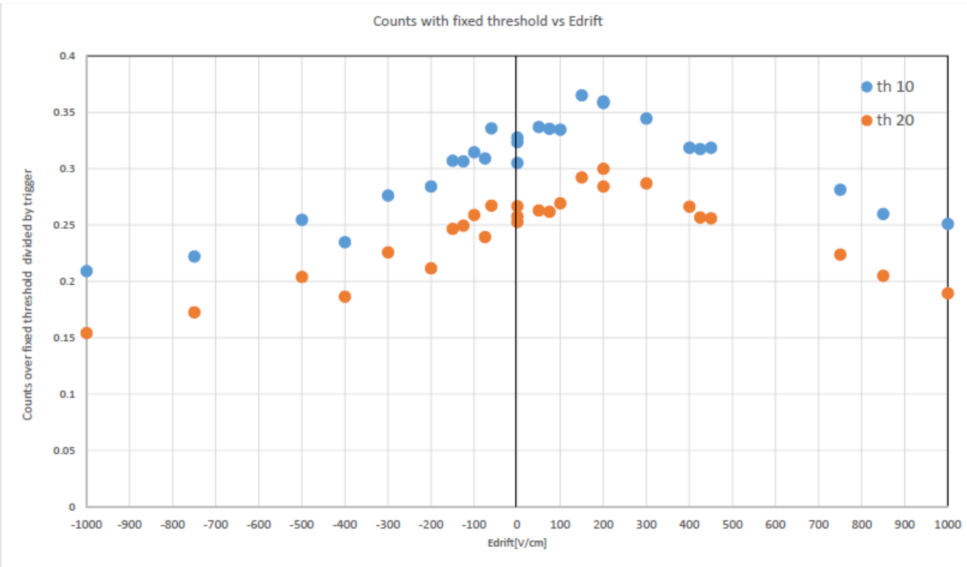
M. Alexeev et al., NIMA 623 (2010) 129



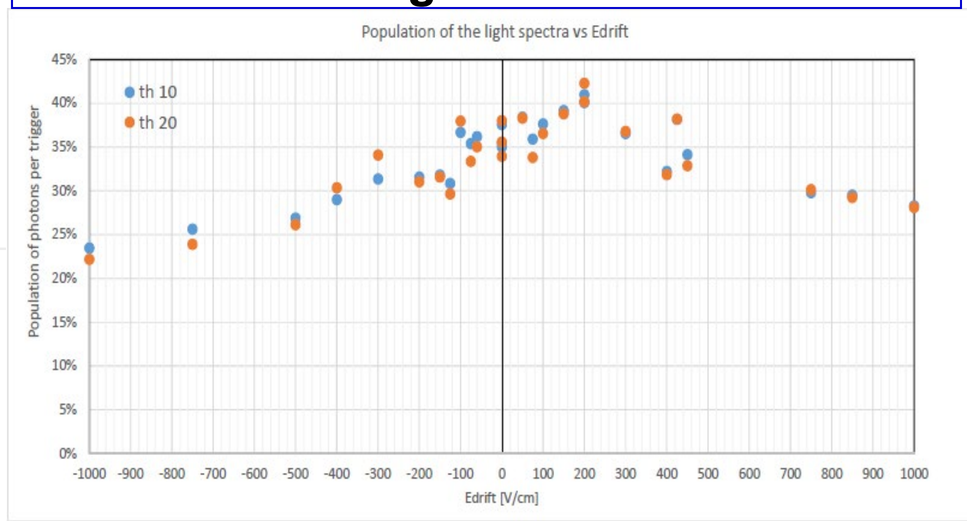
MEASUREMENTS AT THE TEST BEAM

DRIFT SCAN at a test beam

n. of counts above a fix threshold normalized to n. of triggers vs E_{Drift}



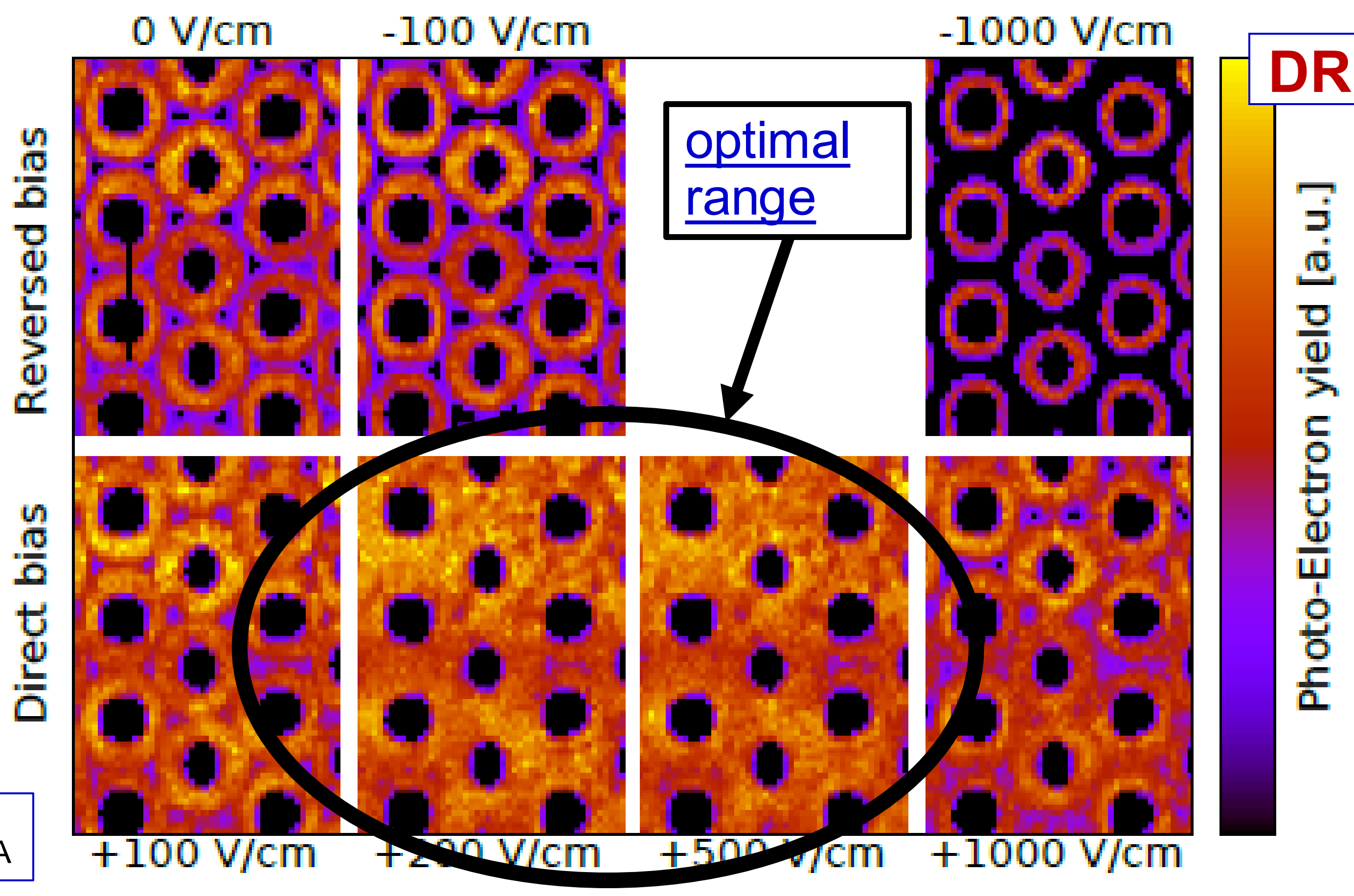
Integral of the exponential spectrum normalized to n. of triggers vs E_{Drift}, two different ranges are fitted



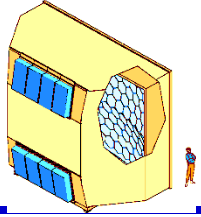
A COMPLETE PICTURE WITH LEOPARD

So far, only information about the best drift field setting

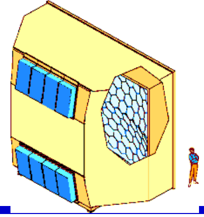
Here, the key question is answered: YES, it is possible to effectively extract photoelectrons from the WHOLE surface



M. Baruzzo et al., Submitted to NIMA



LARGE-SIZE THGEMs



DESIGN ISSUES

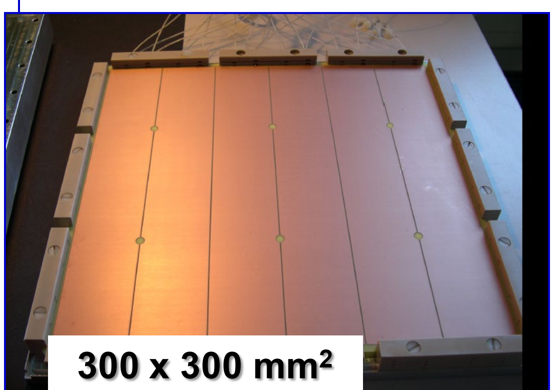
Segmentation

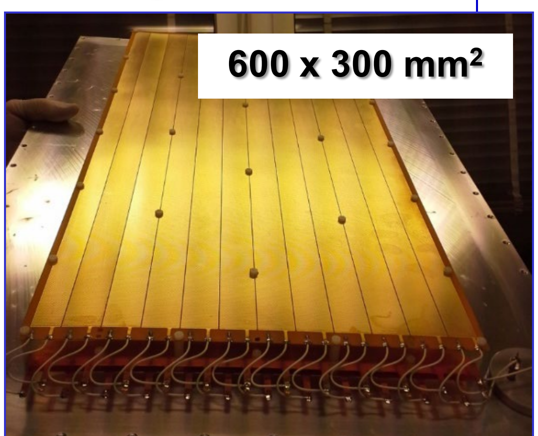
- Limit C → limit discharge energy
- "bad" segments: isolated
- segment surface: O(100 cm^2)

→ C (0.4 mm): O(1nF),
E(1500V): O(1mJ)

→ 300 x 300 mm^2: 6 segments

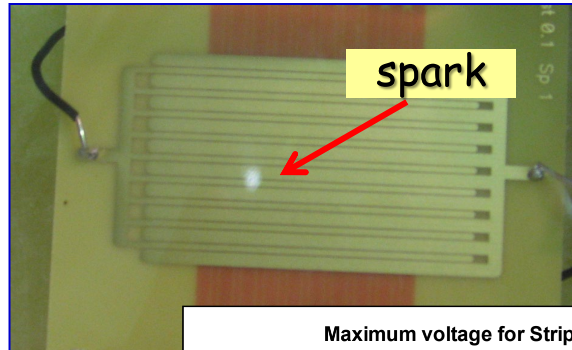
→ 600 x 300 mm^2: 12 segments

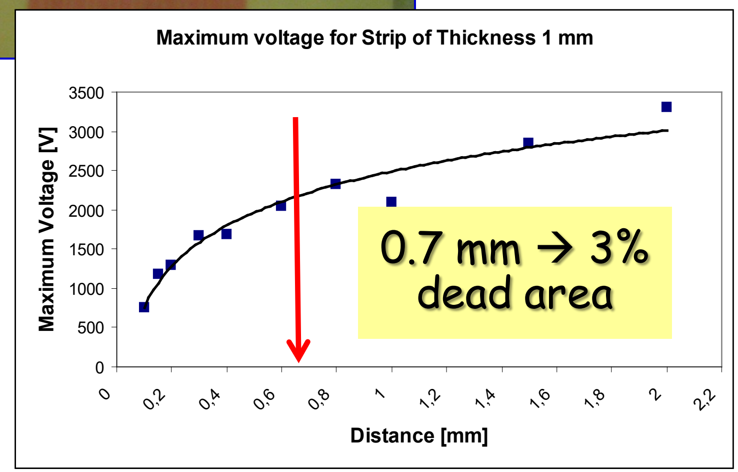


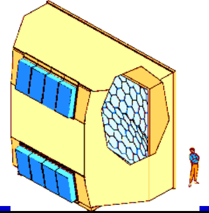


Segmentation studies

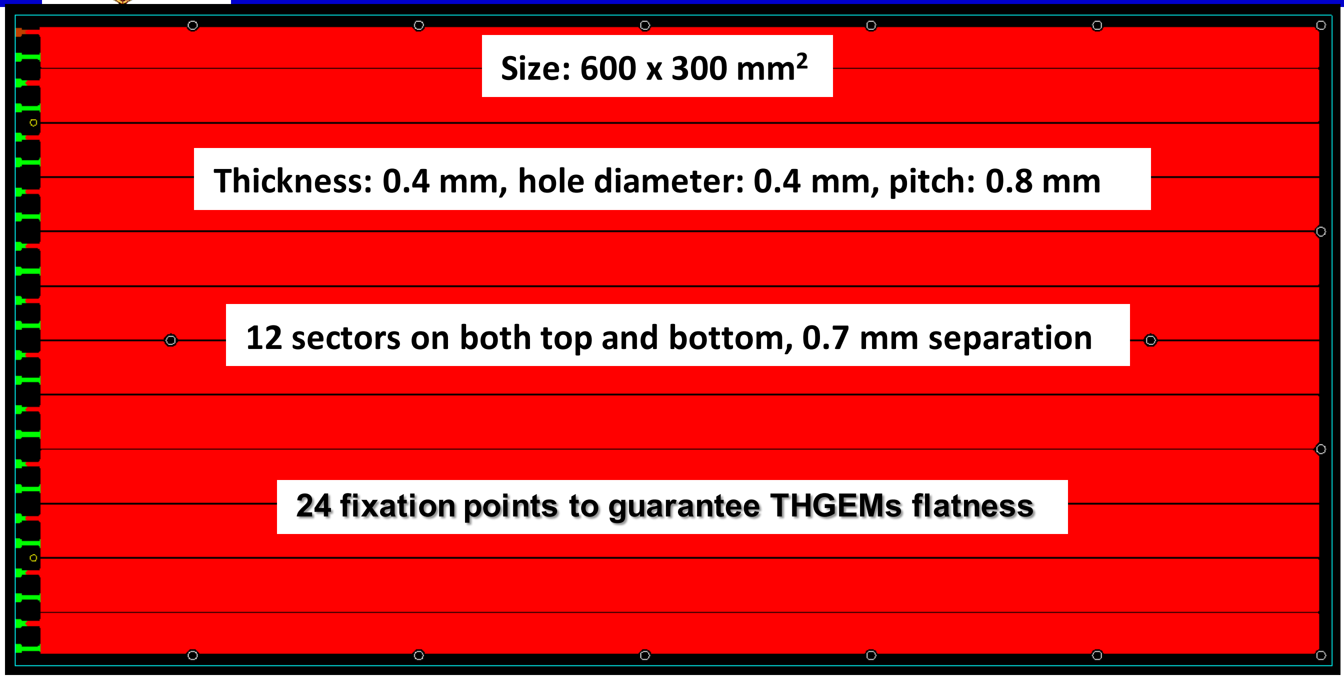
Voltage breakdown measured for 20 different geometries

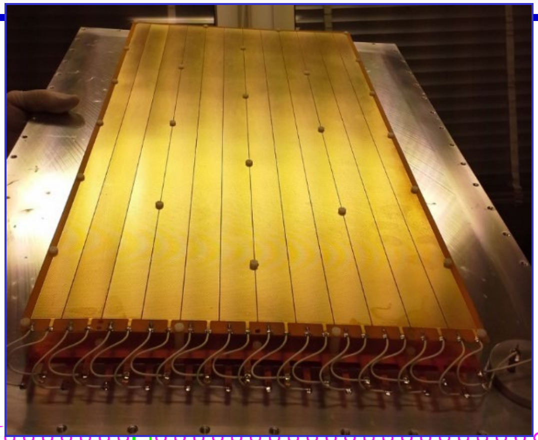


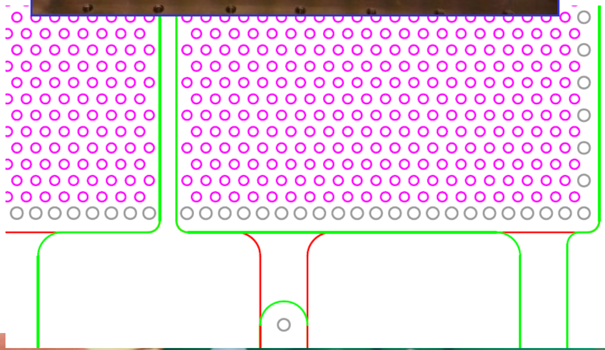


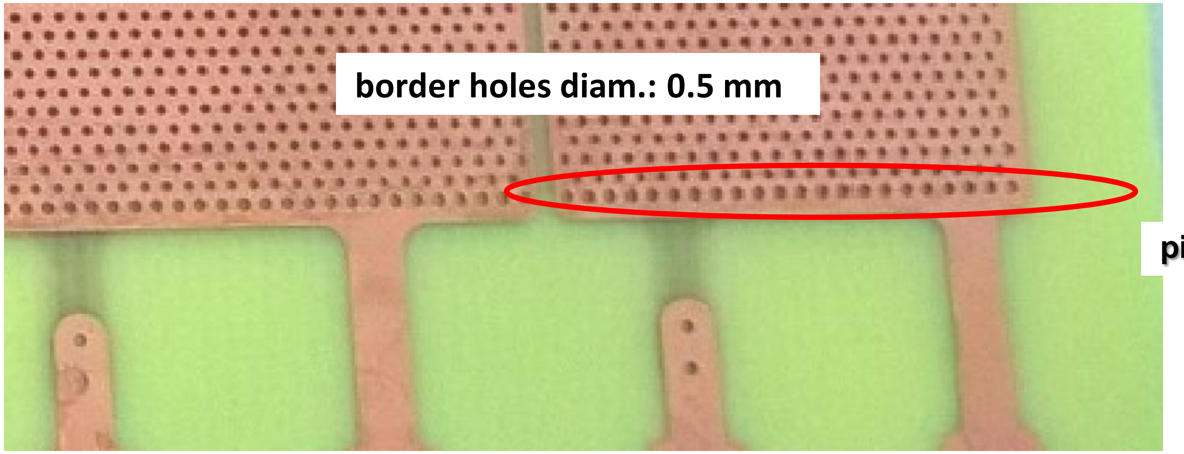


THGEM, FINAL DESIGN

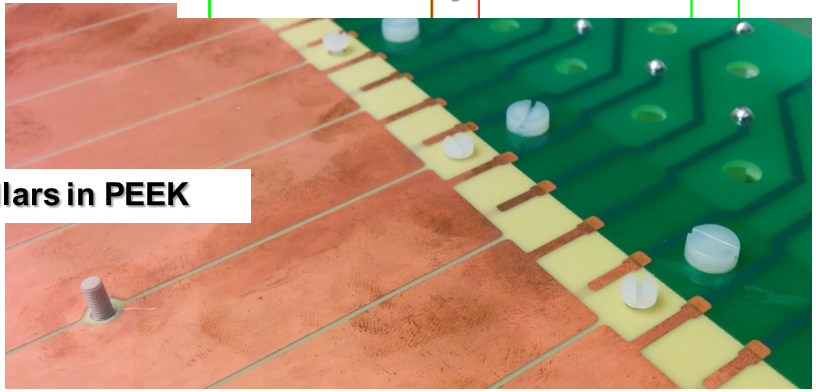




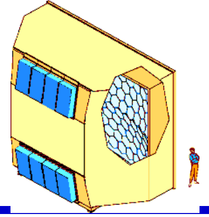




pillars in PEEK

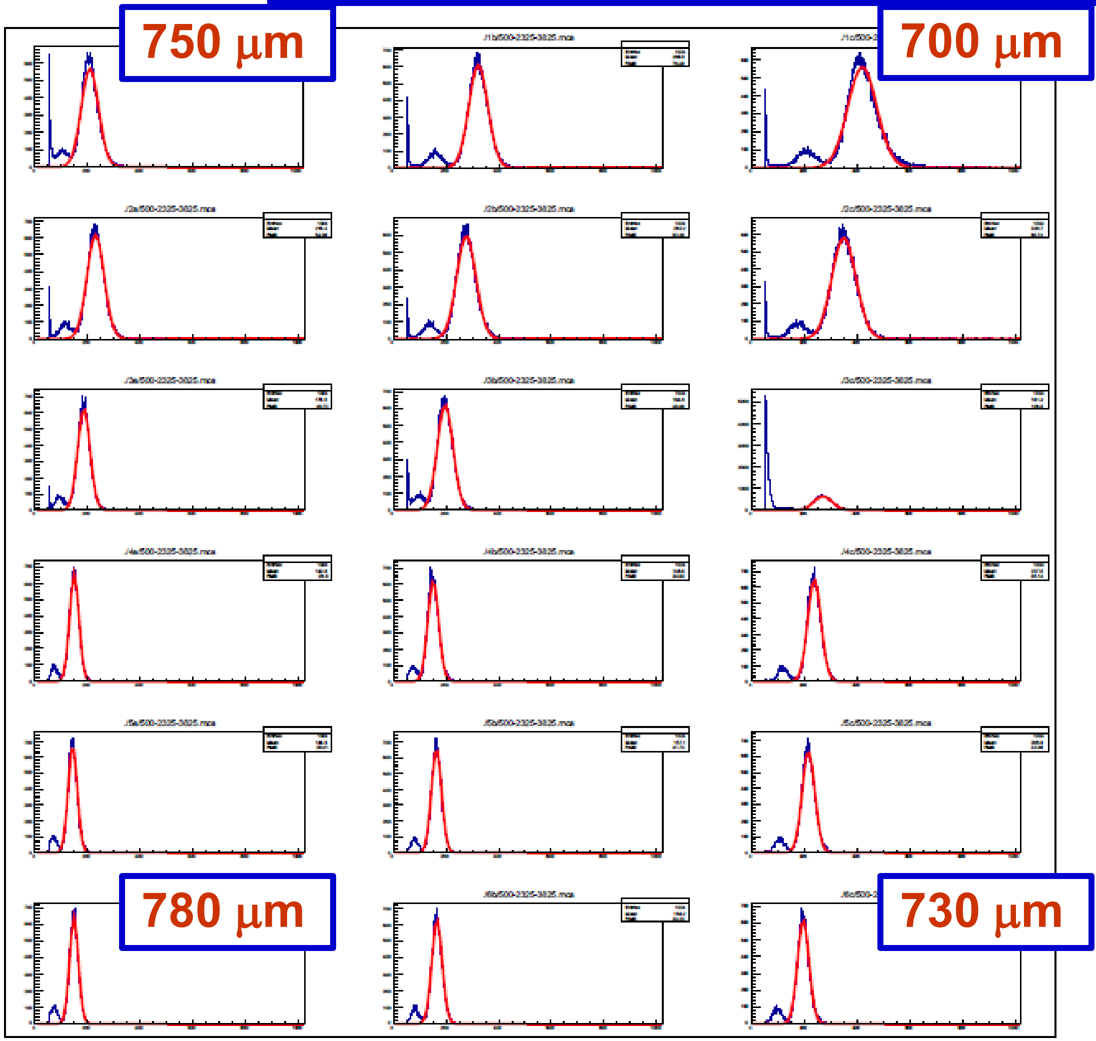


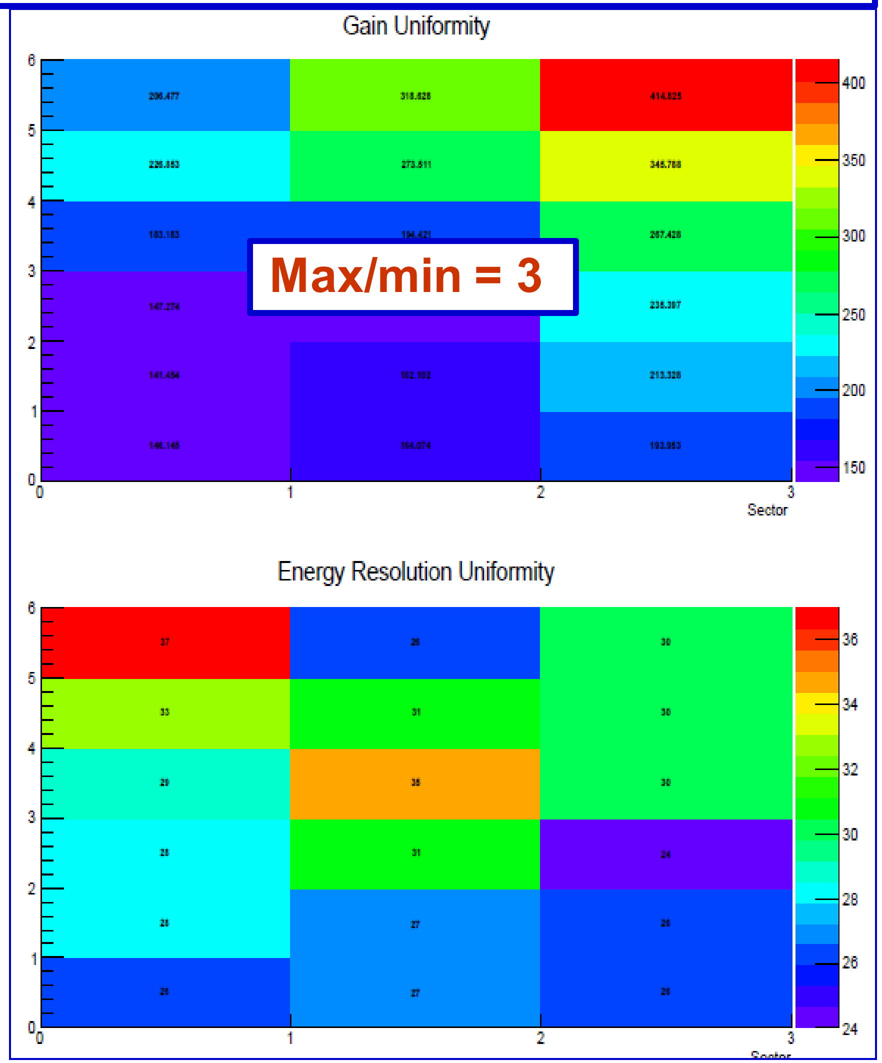
PRODUCTION ISSUES

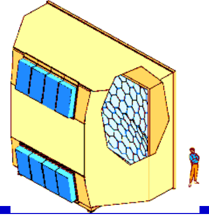


Gain in THGEM 300 x 300 mm^2 (^{55}Fe spectra):

Non-uniformity related to thickness

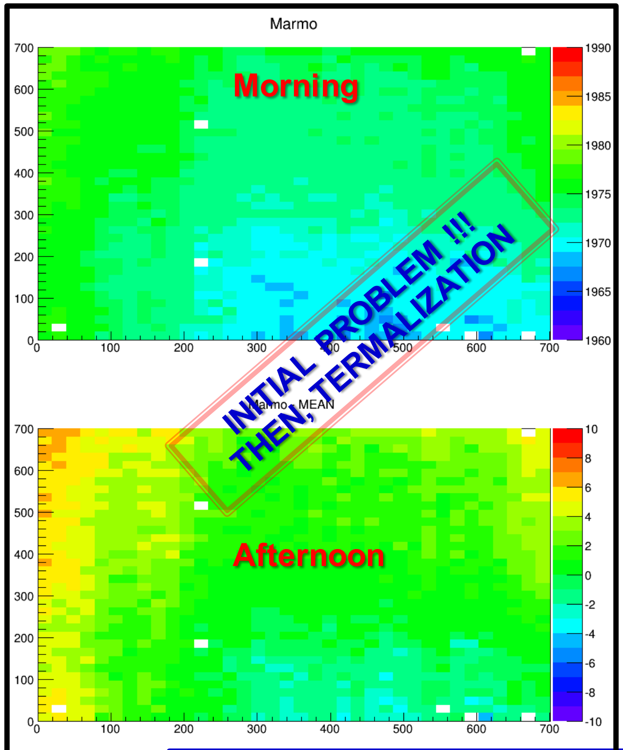




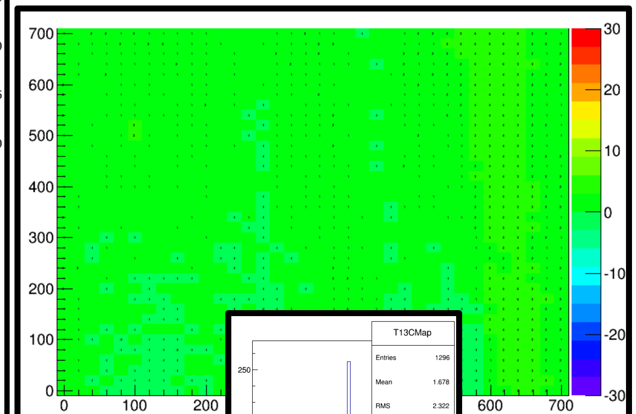


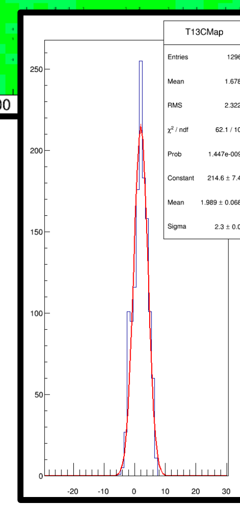
SELECTION OF THE RAW FIBERGLASS FOILS

The Mitutoyo Euro CA 776 Coordinate Measuring Machine (CMM)

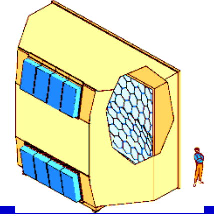


With **termalization** the difference between two reference plane measurements at the beginning and at the end of the day gives a distribution around zero.





Foils blocked onto the reference table by underpressure



SELECTION OF THE RAW FIBERGLASS FOILS

First step: remove a 20 cm wide frame all around each foil

- **Analysis program is complete, and have fast running time (~20 minutes)**

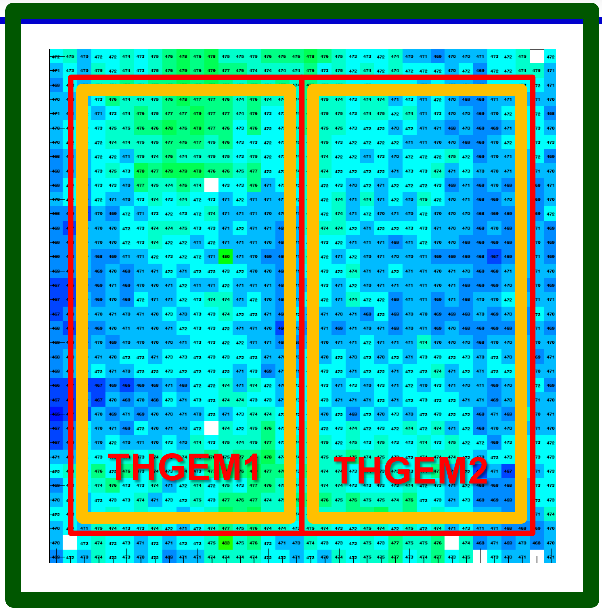
========================

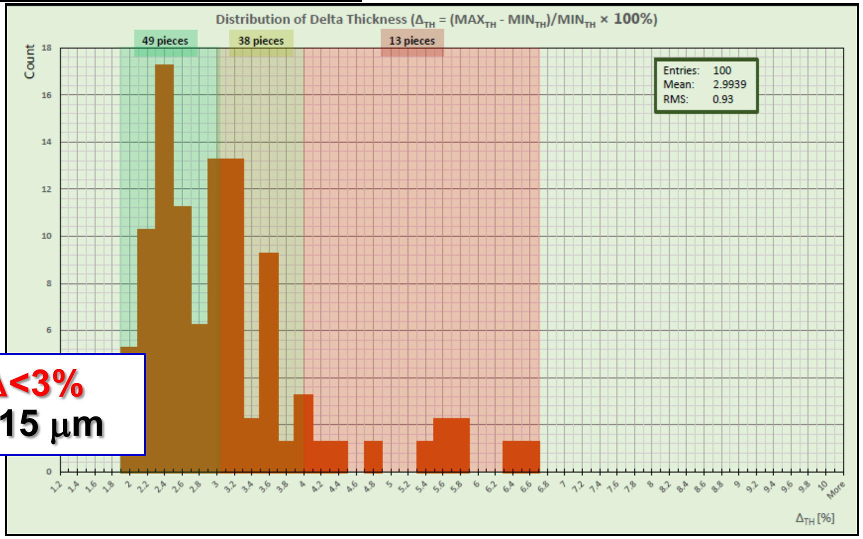
- **Measured area: 70 x 70 cm^2**
- **1296 (36 X 36) points**
- **Average THICKNESS = 470μm**
- **All 50 foils measured & analyzed**
- **300 x 600 mm^2 area has sigma thickness between 2 and 3 μm.**
- **The Delta THICKNESS is between 10 and 20 μm.**

- **PCB Area: (Here Thick green box)** $= 800 \times 800\ mm^2$;
- **Measured area: (2D color plot)** $= 700 \times 700\ mm^2$;
- **needed area: (Thin Red boxes)** $= 320 \times 620\ mm^2$;
- **THGEM area: (Thick yellow boxes)** $= 287 \times 581\ mm^2$;
- ***Calculate:***

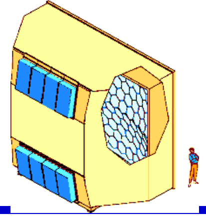
$$\Delta_{TH} = \frac{MAX_{TH} - MIN_{TH}}{MIN_{TH}} \times 100\%$$

- **Pieces ranked according to the values of Δ_{TH}**





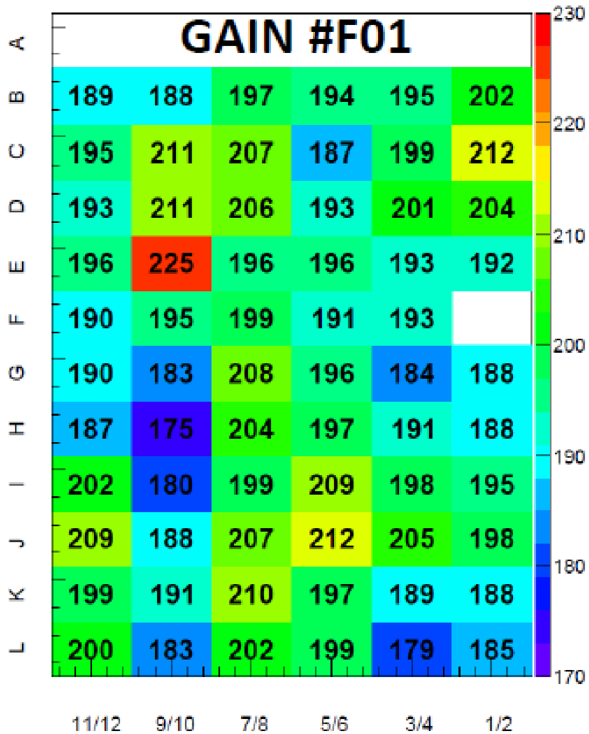
49 p.cs: 2%<Δ<3%
→ Max-Min < 15 μm

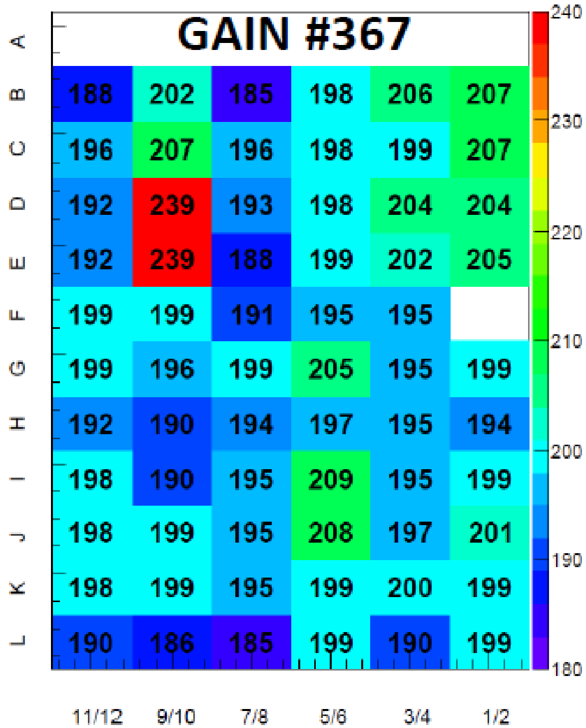


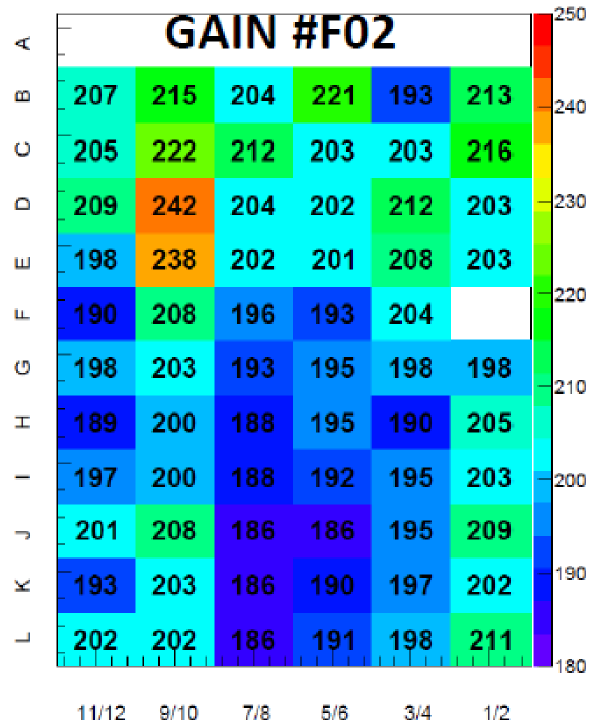
600 x 300 mm² THGEMs

RESULTING UNIFORMITY from GAIN MAPS (^{55}Fe spectra)

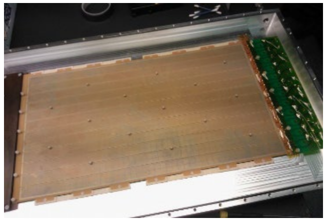
UNIFORMITY r.m.s. : 7 %



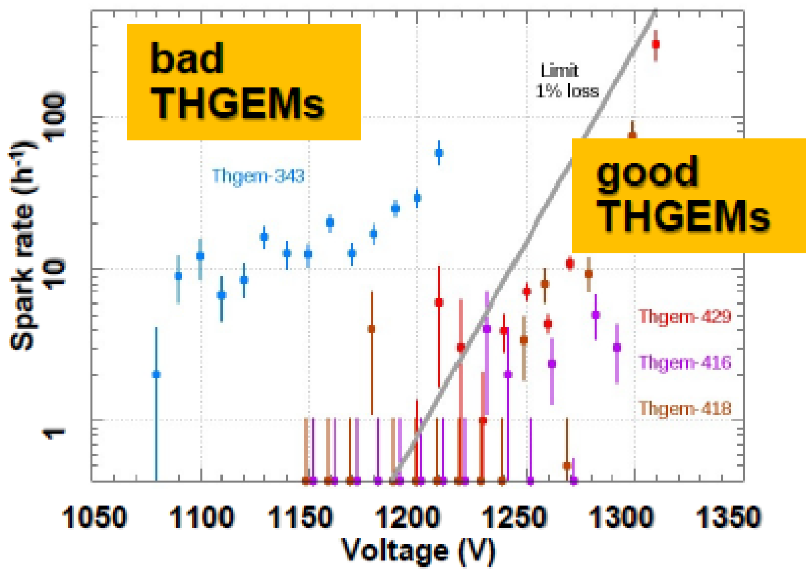


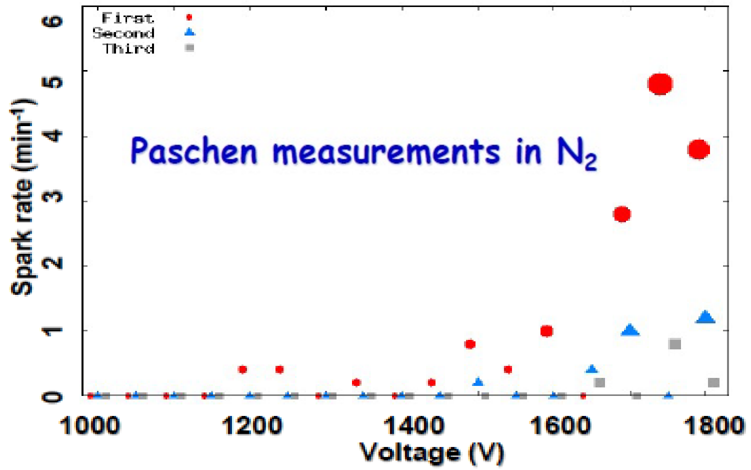


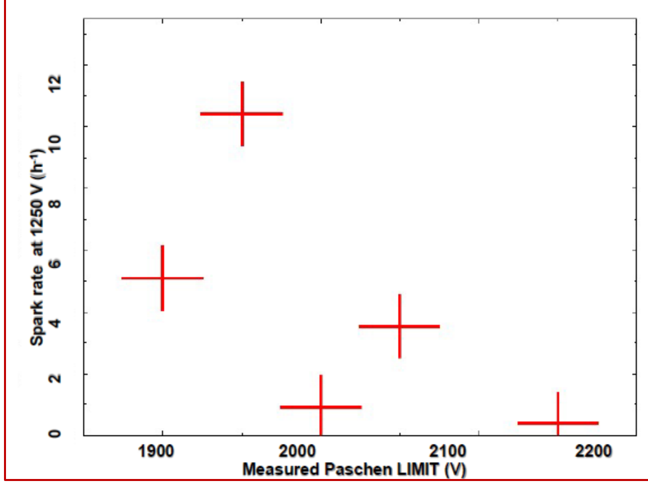
DISCHARGE RATES in single layer THGEM



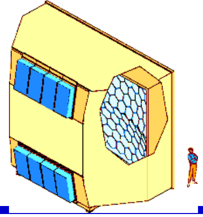
X-ray THGEM test to access gain uniformity (<7%)and spark behaviour



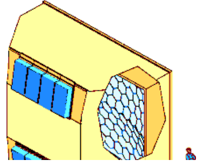




Correlation of PASCHEN LIMIT vs SPARK RATES



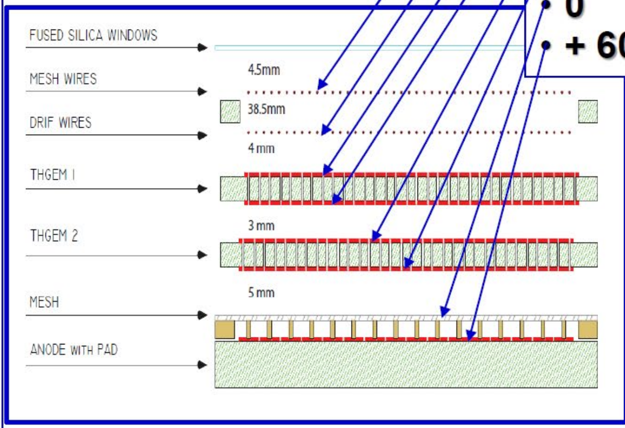
THGEM PERFORMANCE in COMPASS RICH



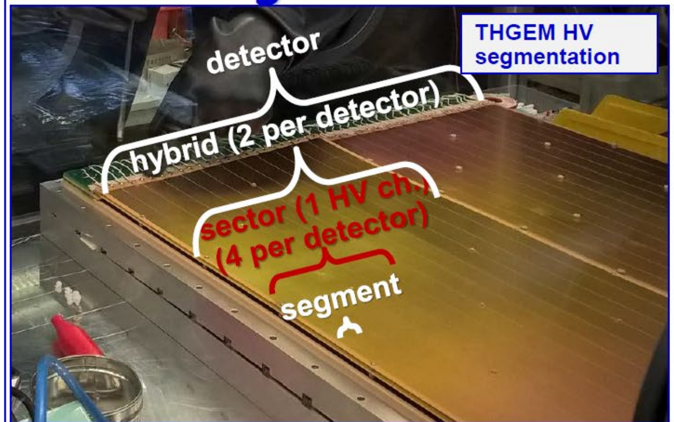
HV supply

- **Typical HV values**

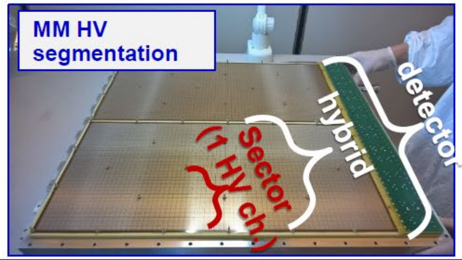
- - 300 V
- -3400 V
- -3200 V
- -2000 V
- -1700 V
- - 500 V
- 0
- + 600 V



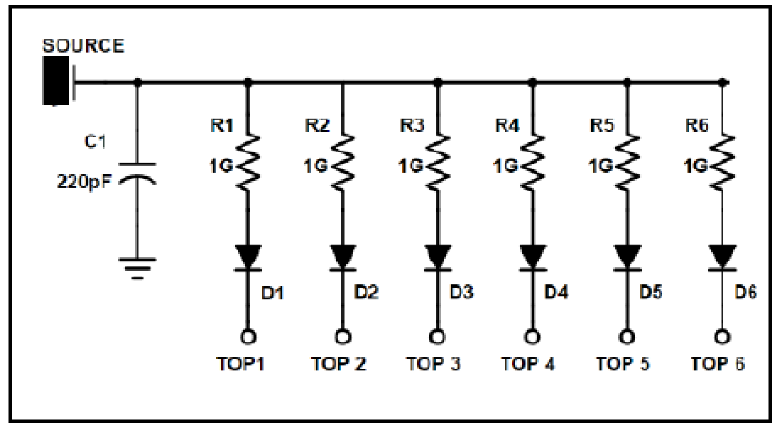
- **HV segmentation**

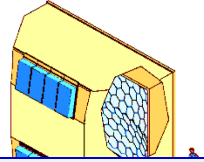


So far:
22 HV ch.s per detector, 4 detectors



THGEM, top face
(bottom is analogous)

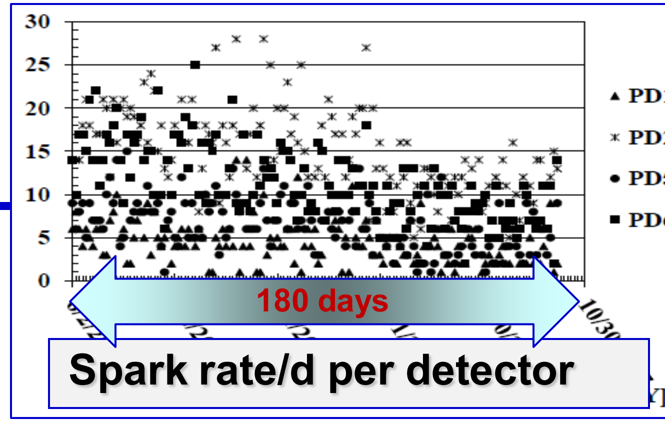




HV CONTROL

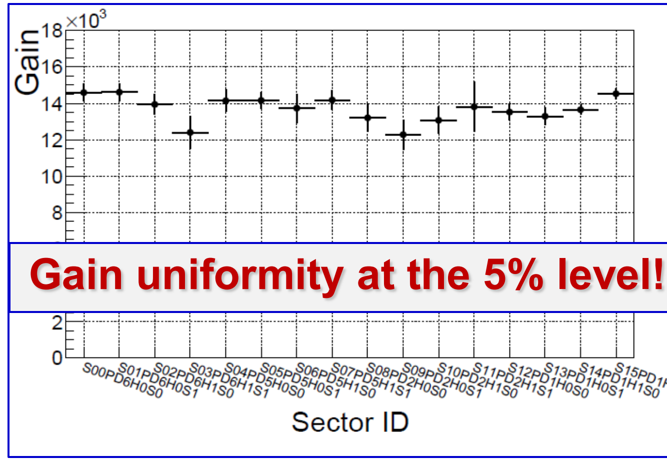
MAIN CHALLENGES

- In total 136 HV channels with highly correlated values
- stabilize and equalize the gain in the 16 sectors
- Gain stability vs P, T:
  - G = G(V, T/P)
  - $\Delta T = 1^oC \rightarrow \Delta G \approx 12\ \%$
  - $\Delta P = 10\ mbar \rightarrow \Delta G \approx 20\ \%$
- THE WAY OUT:
  - Compensate T/P variations by V



180 days

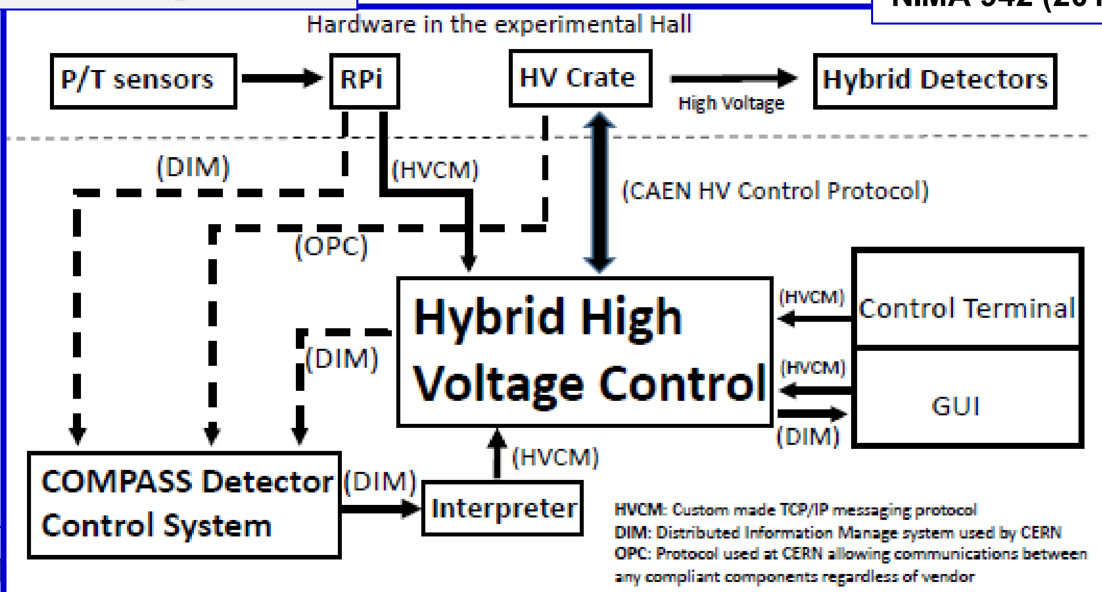
Spark rate/d per detector

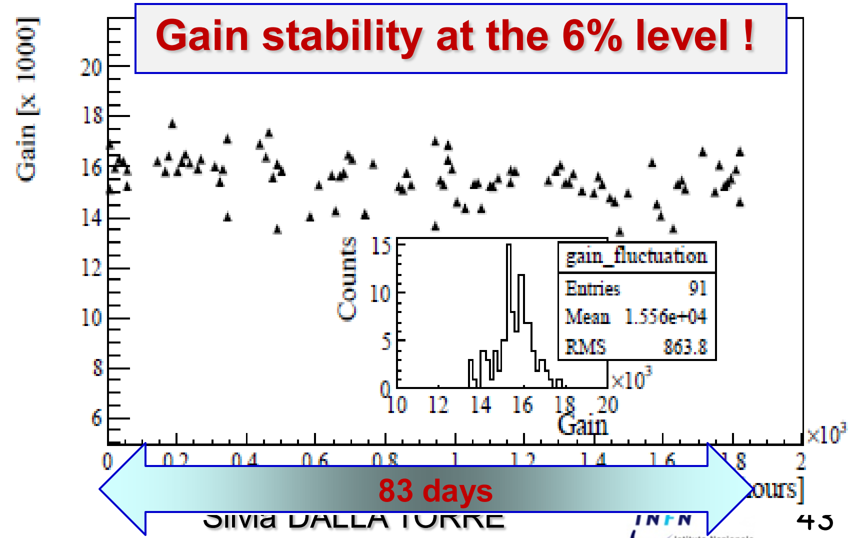


Gain uniformity at the 5% level!

The HV system

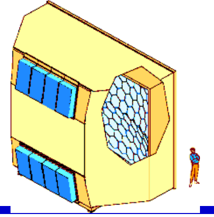
J. Agarwala et al., NIMA 942 (2019) 162378



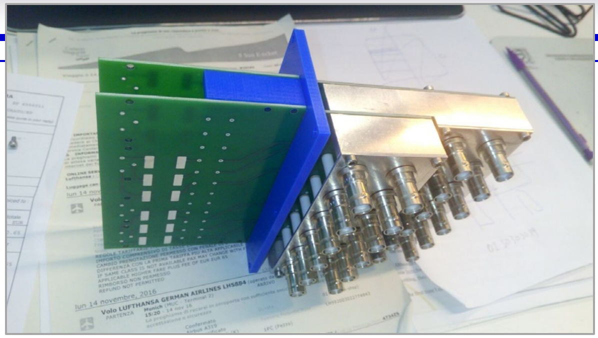


Gain stability at the 6% level !

83 days



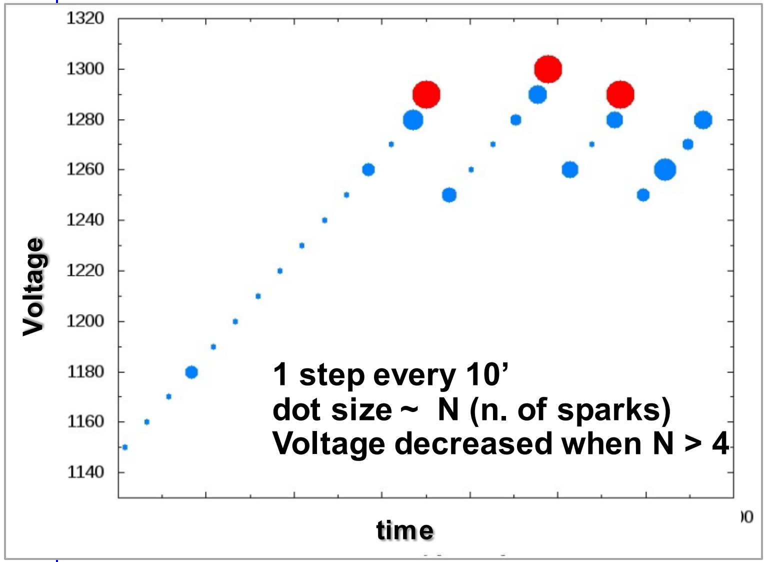
ELECTRICAL STABILITY ISSUES, in situ



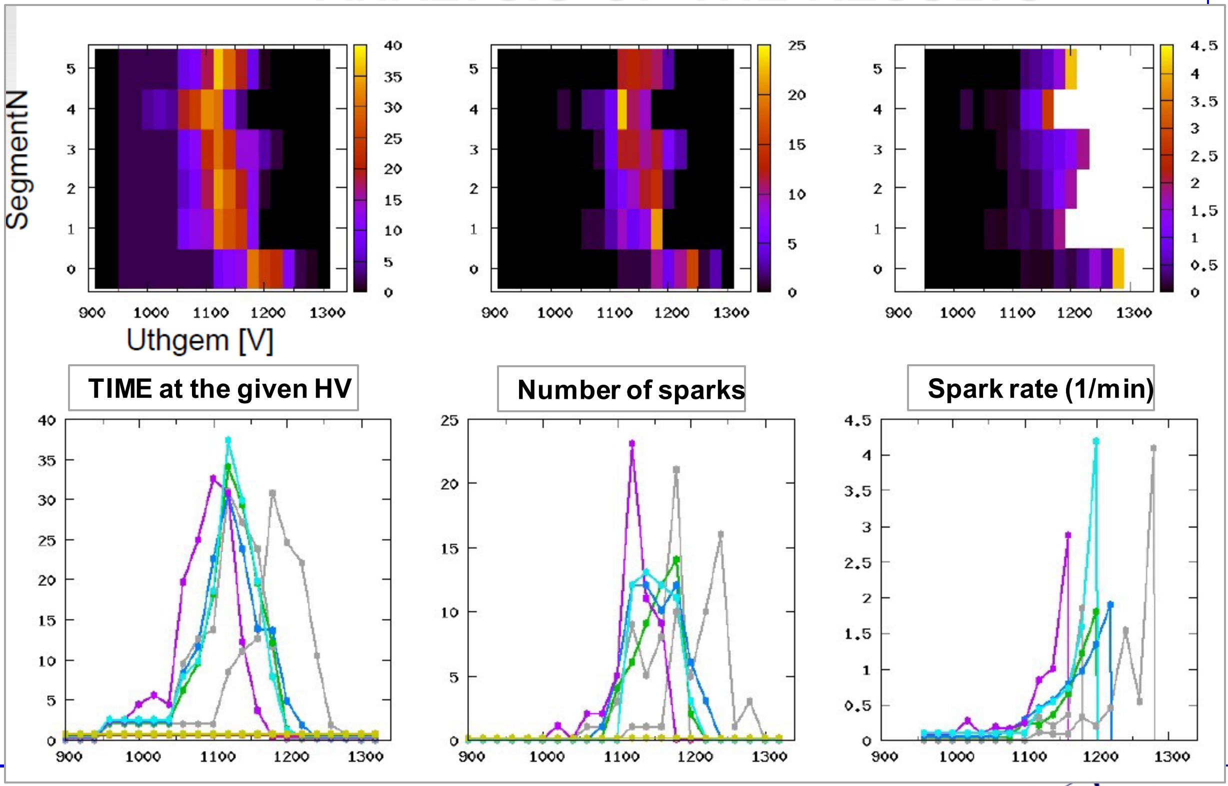
Studying segment by segment in situ

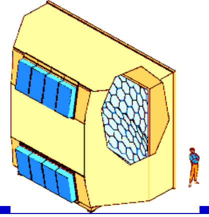
- 2 dedicated voltage distribution boxes built
  - 6 segments per box, independent HV supply
- Dedicated software control tool

THE TEST LOGICS

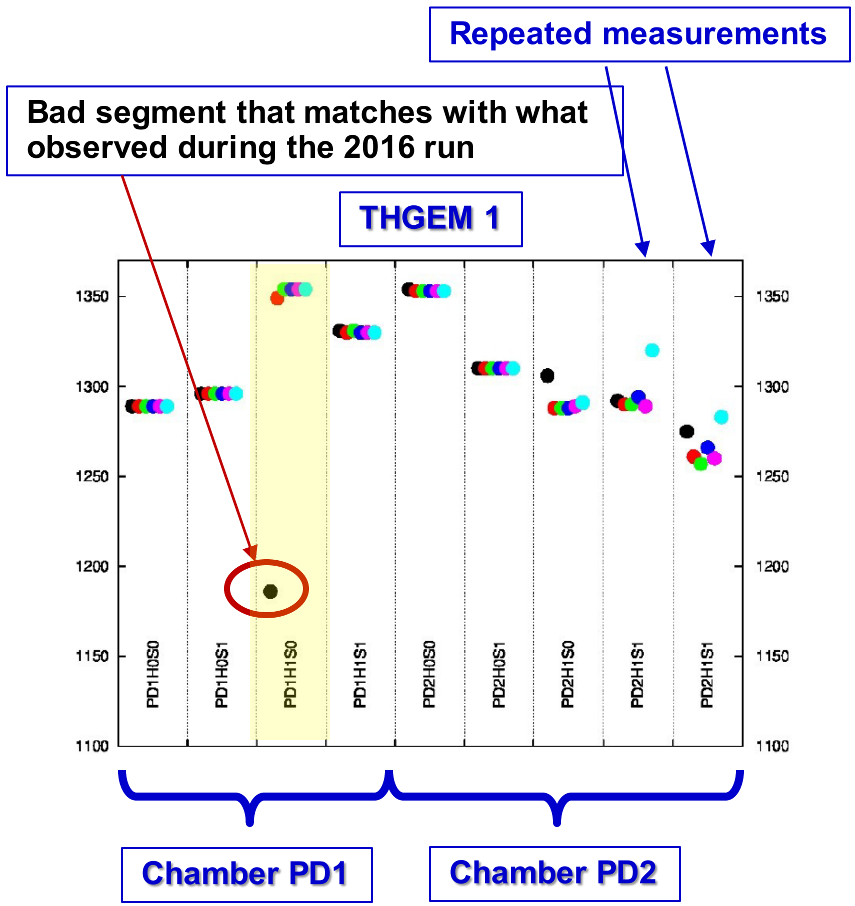


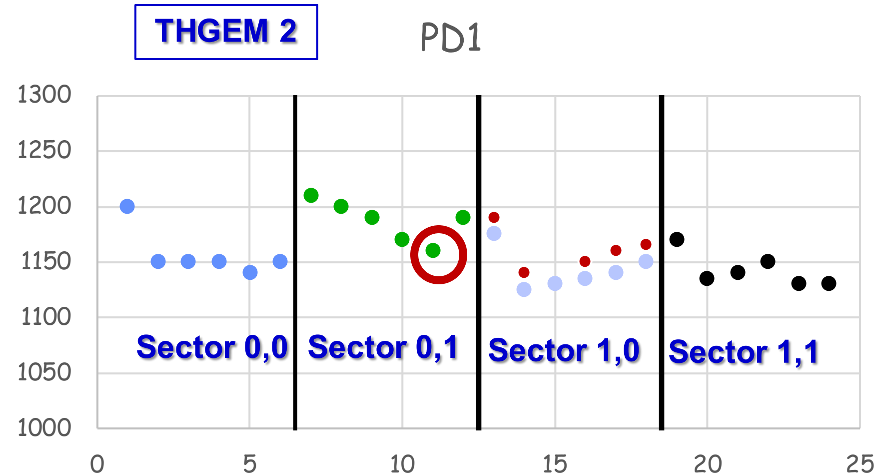
ANALYSIS OF THE RESULTS

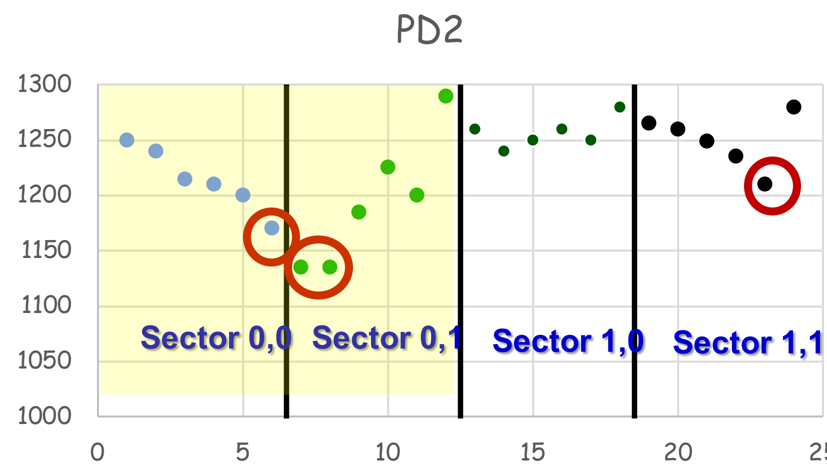


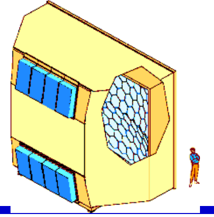


Feeble sectors, study of the bottom chambers, powered by dedicated HV channels









ELECTRICAL STABILITY ISSUES, more

Feeble sectors, study of the bottom chambers, pow... ...nnels

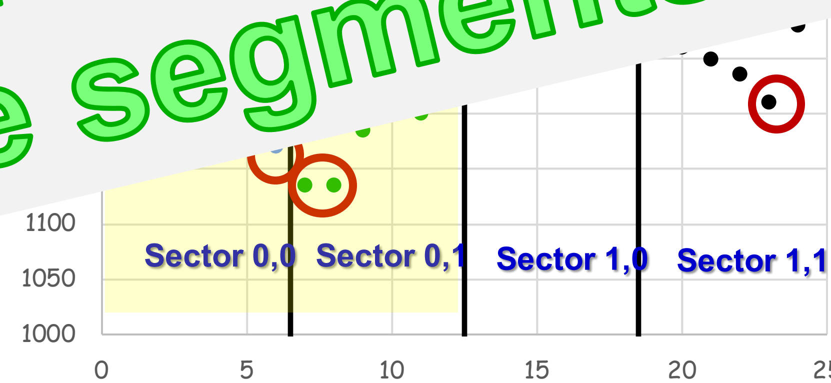
Repeated measu...

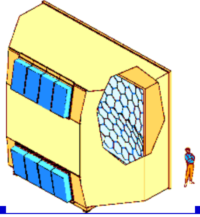
Bad segment that mat...
observed du...

The long term operation in COMPASS RICH has confirmed the correct identification of the feable segments

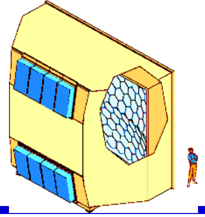
12..
1150
1100

C... ...D2

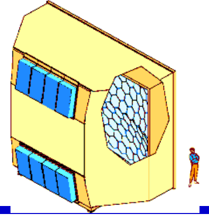




THANK YOU

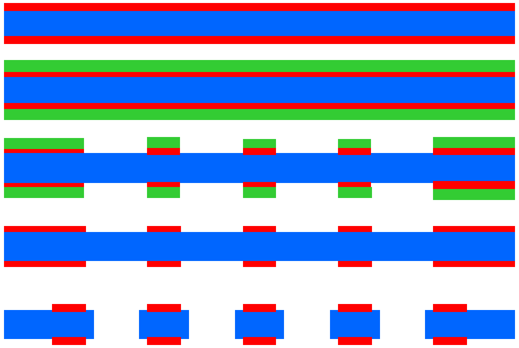


MORE INFORMATION

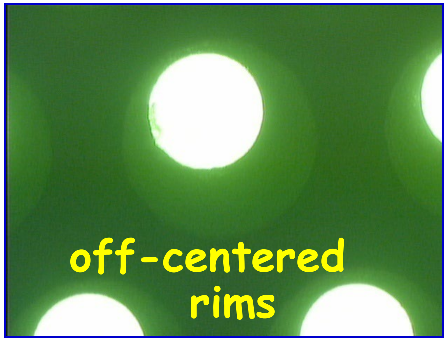


THGEM PRODUCTION

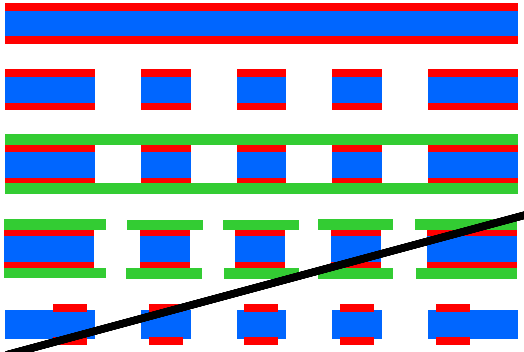
1)traditional



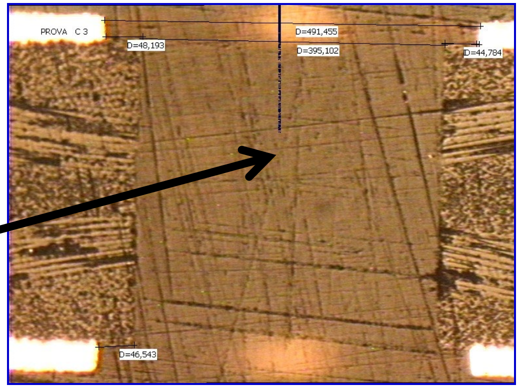
etching before drilling



2) large rim



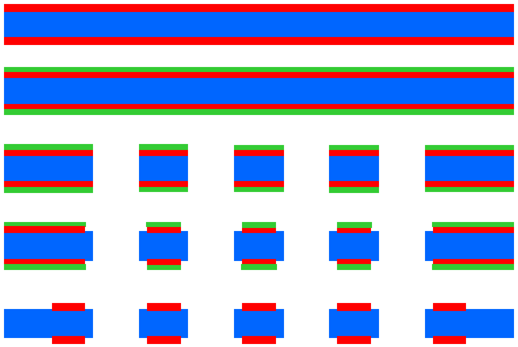
metallographic section



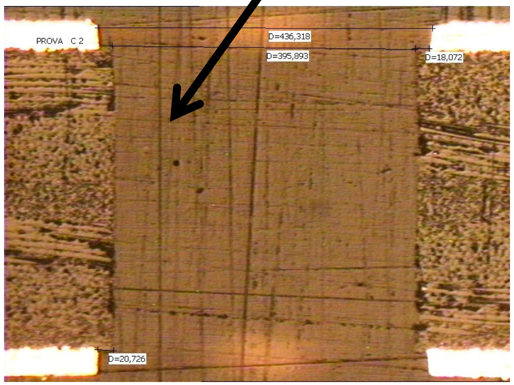
100 µm rim

CERN approach
R. De OLIVEIRA

3) small rim

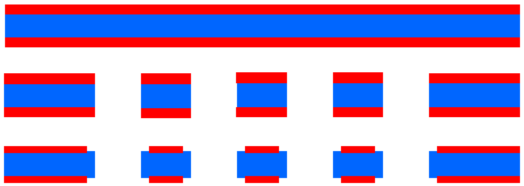


20 µm galvanic tin
instead of photo-resist



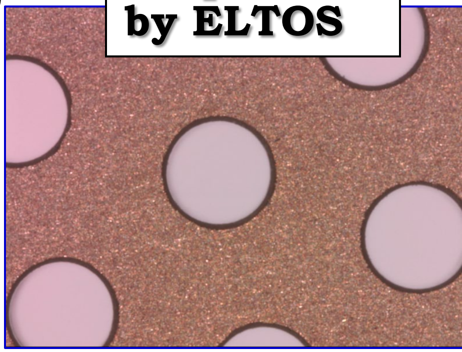
25 µm rim

4) global etching



uniform and smooth

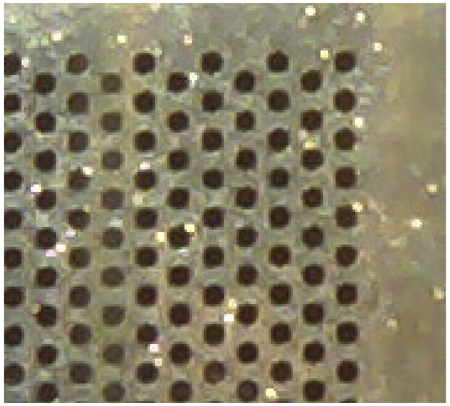
Proposed by ELTOS

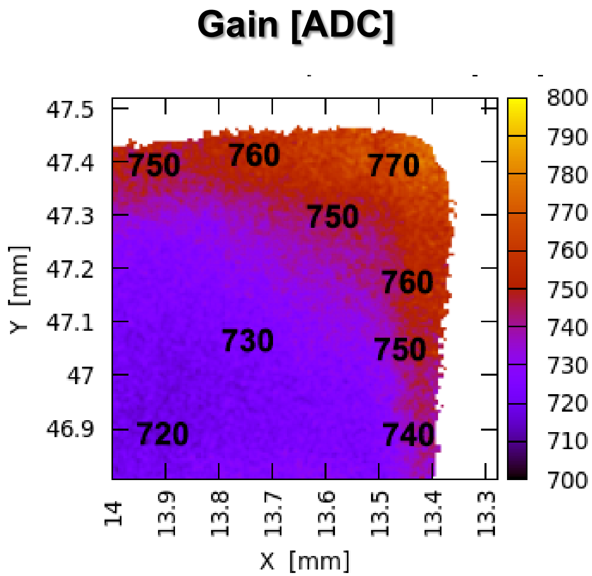


Microetching: very small rim

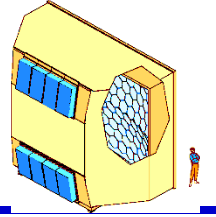
LARGER GAIN AT THE BORDERS

standard GEM foil



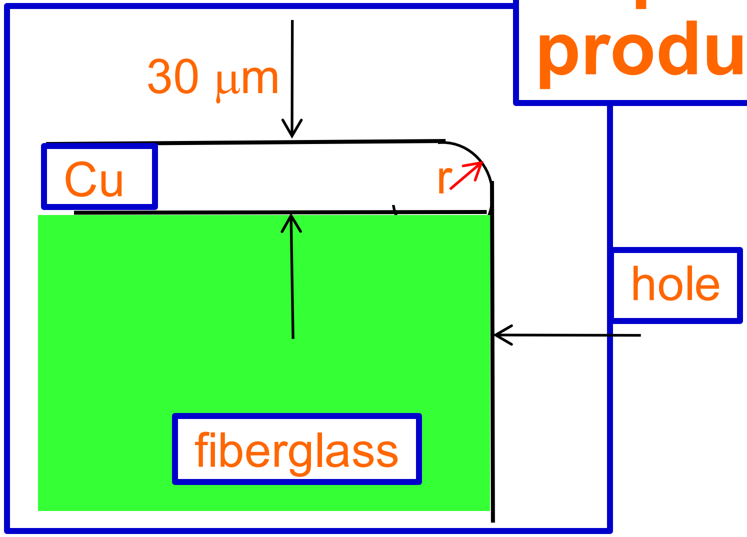


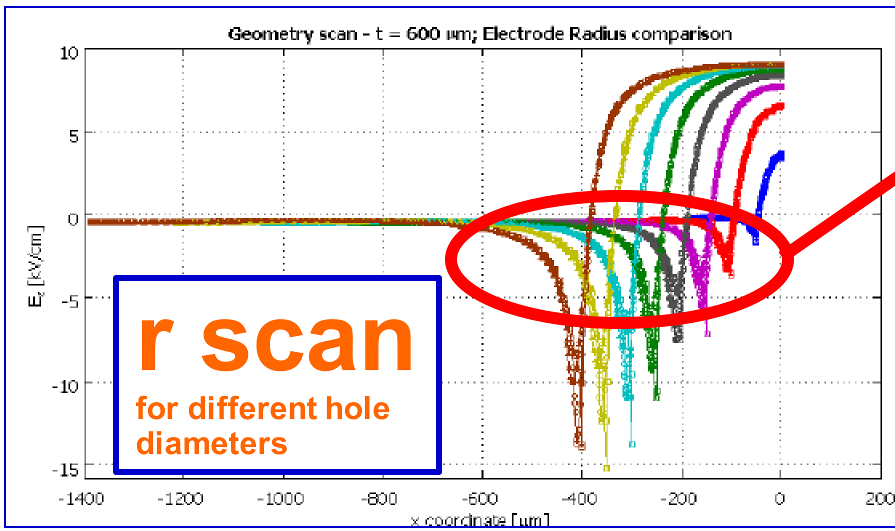
G. NYITRAI et al.,
AIDA-2020 3Rd annual meeting, 2018

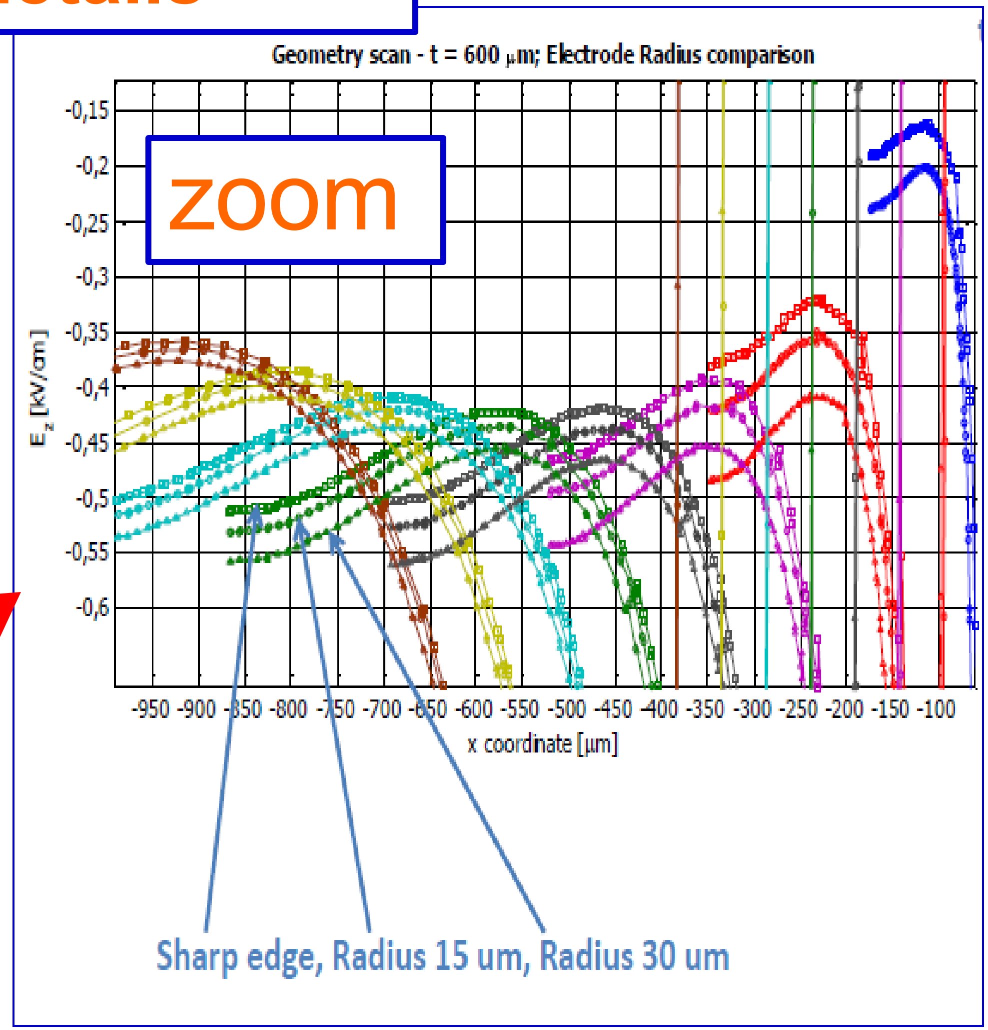


PRODUCTION DETAILS

Dependence from the production details





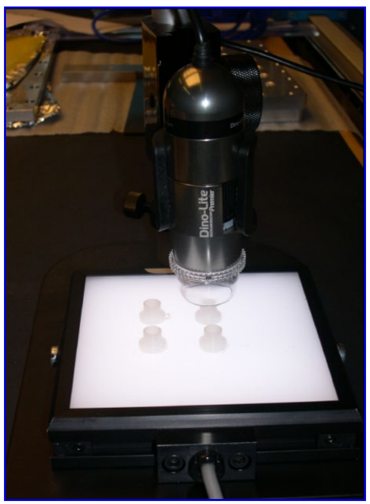


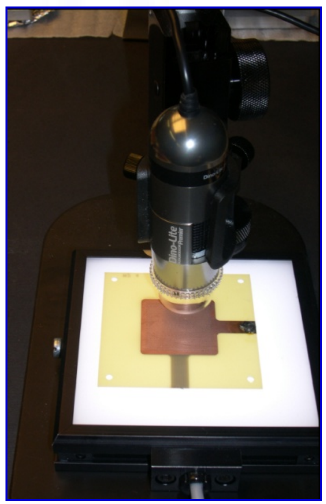
MEASUREMENT OF THE RIM SIZE

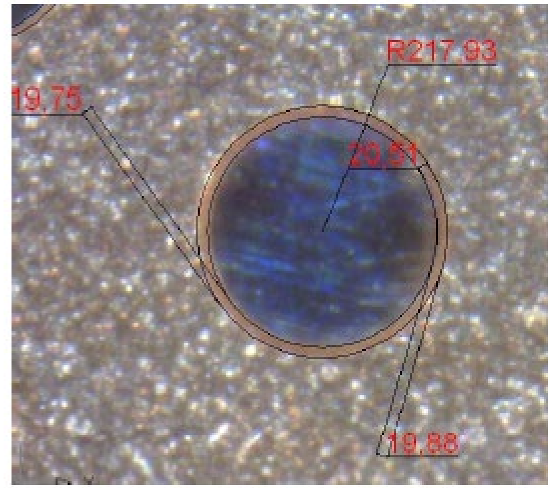
Microscope with direct USB interface to any PC:

Dino-Lite AM7013 MZT

(x 250, 5 Mpixels)







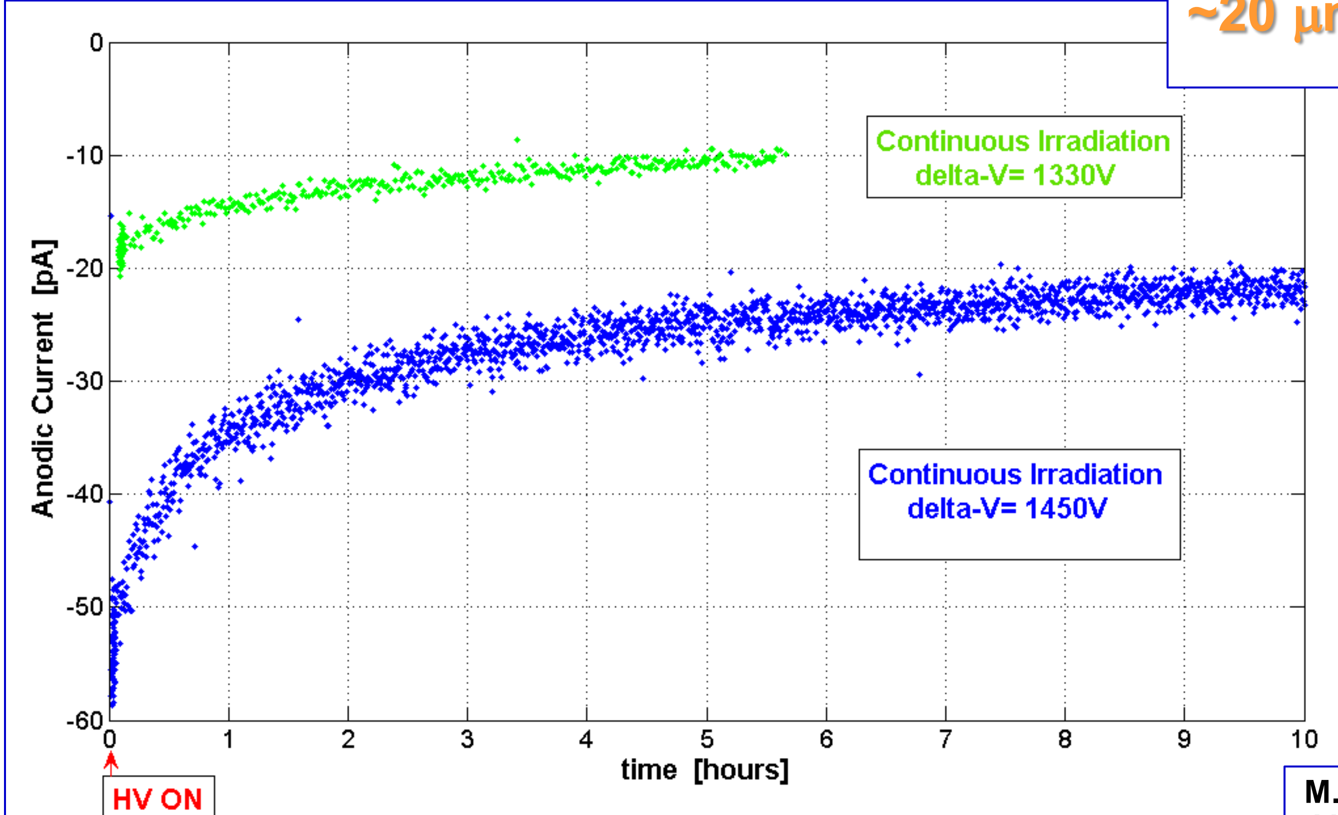
RIM measurement, method:

- **Microscope Image**
- **imported in AutoCad**
- **fit of the circles**
- **scale calibration using the radius of the hole (mechanics, i.e. good precision)**

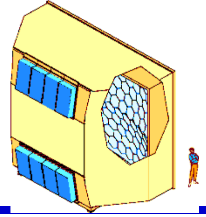
RIM & HV

- the absolute scale of the effect depends on HV
- the relative effect is ~ independent from the applied HV

~20 μm rim



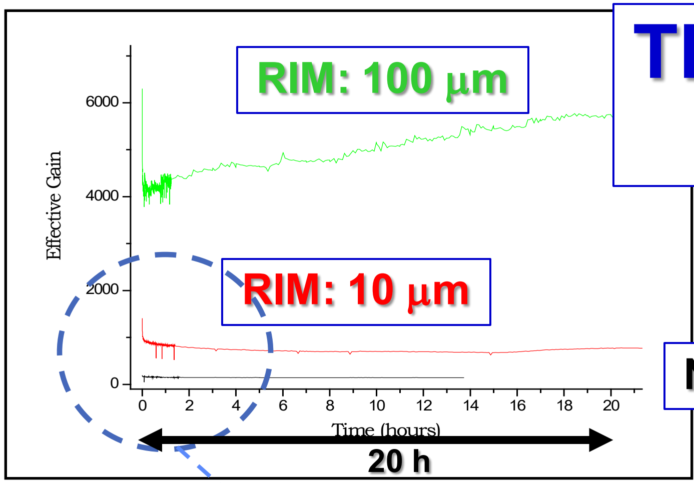
M. Alexeev et al.,
JINST 10 (2015) P03026



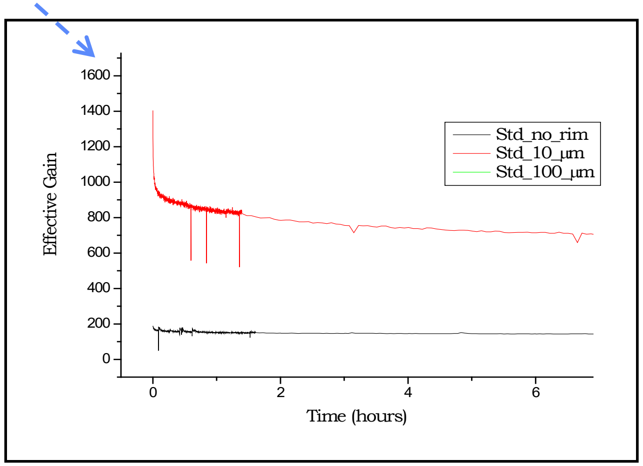
UNDERSTANDING THE RIM

X-ray measurements

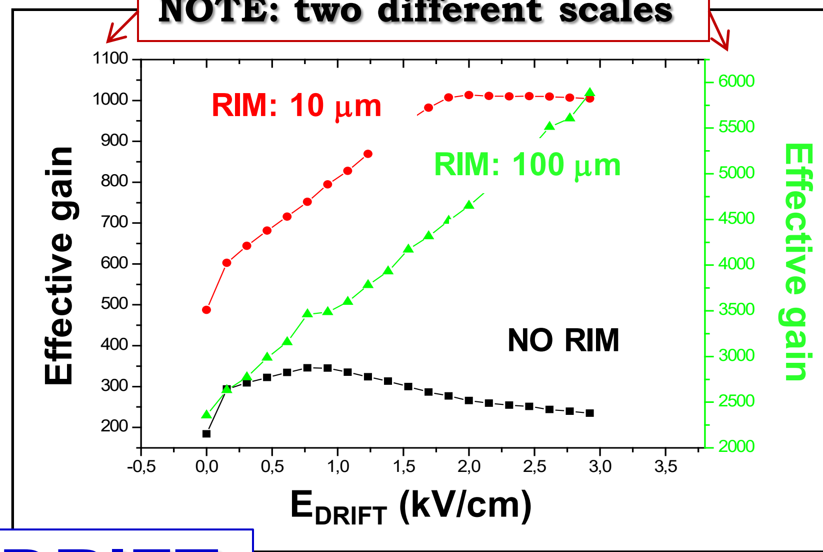
THGEM & RIM



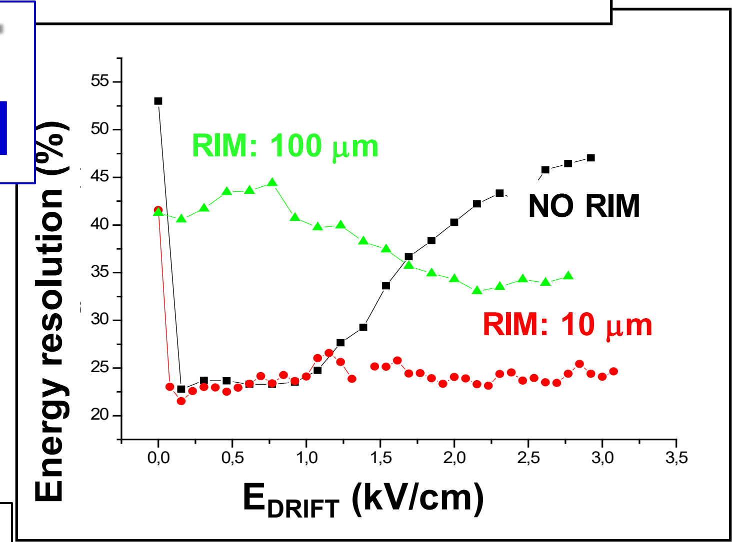
zoom



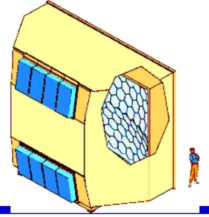
NOTE: two different scales



DRIFT SCAN



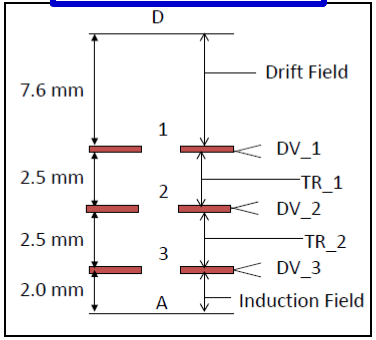
S. Dalla Torre et al.,
IEEE – NSS 2008 , Dresden 19-25/10/2008



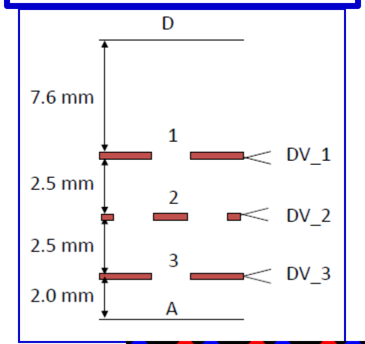
M. Alexeev et al., JINST 8 (2013) P01021

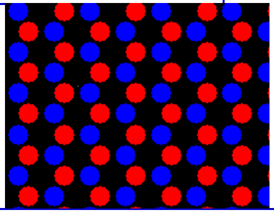
IBF: Ion Back Flow - good reduction by hole staggering

A -aligned

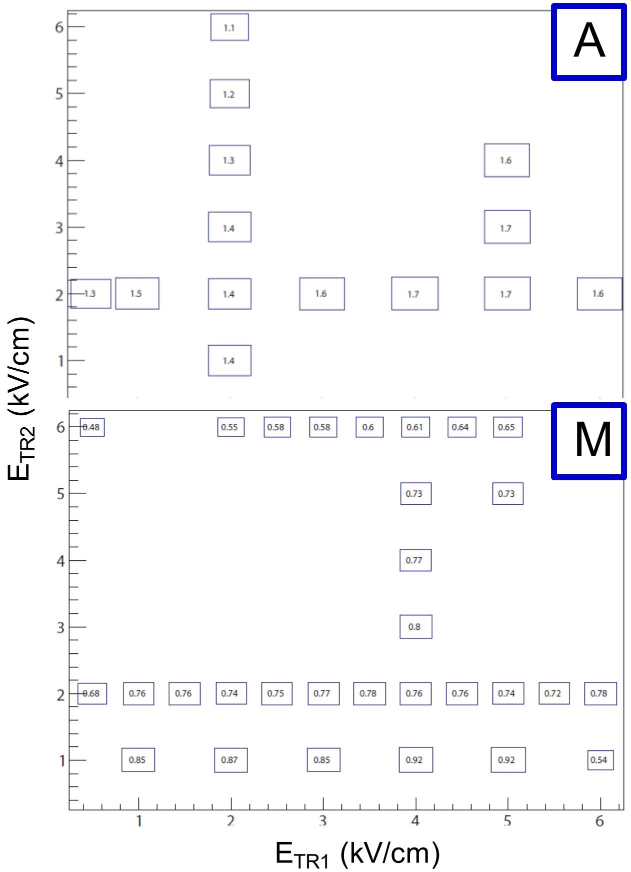


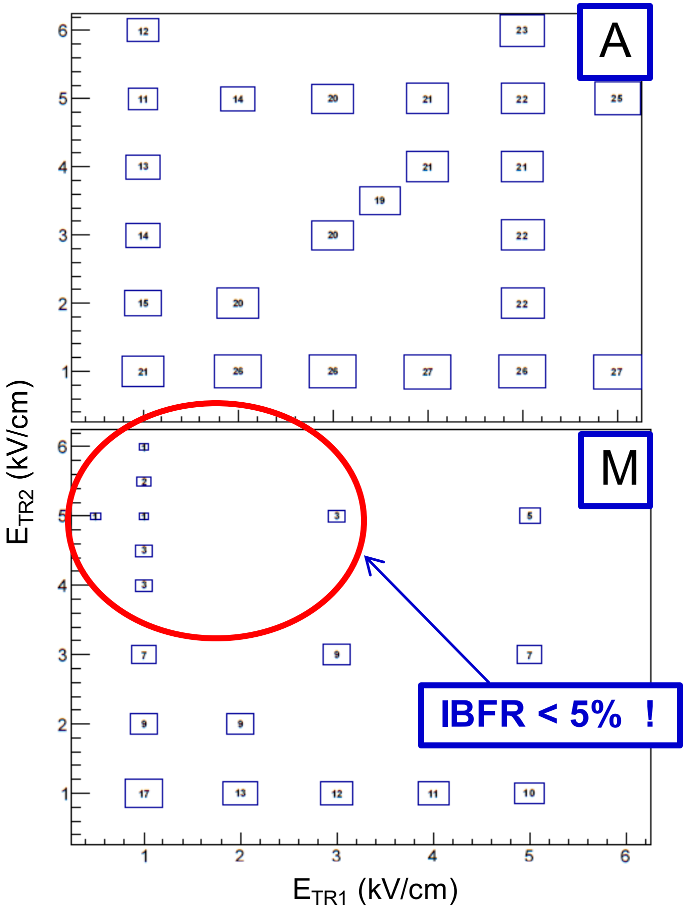
M -misaligned



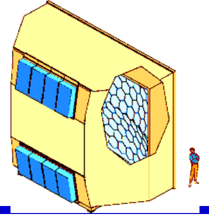


Same voltages





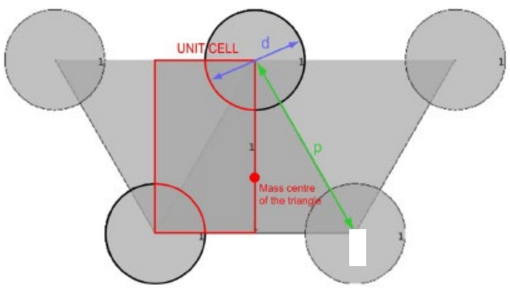
Lower gain (~ 50%) : high V to recover



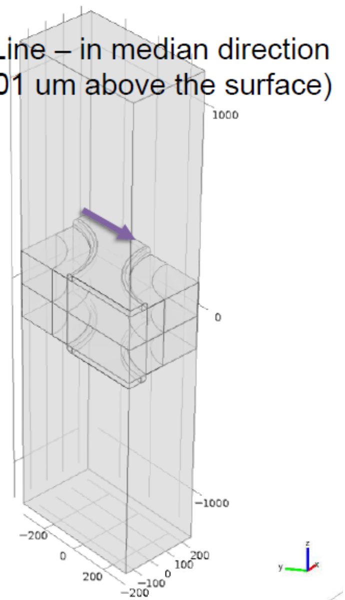
ELECTROSTATIC CALCULATIONS

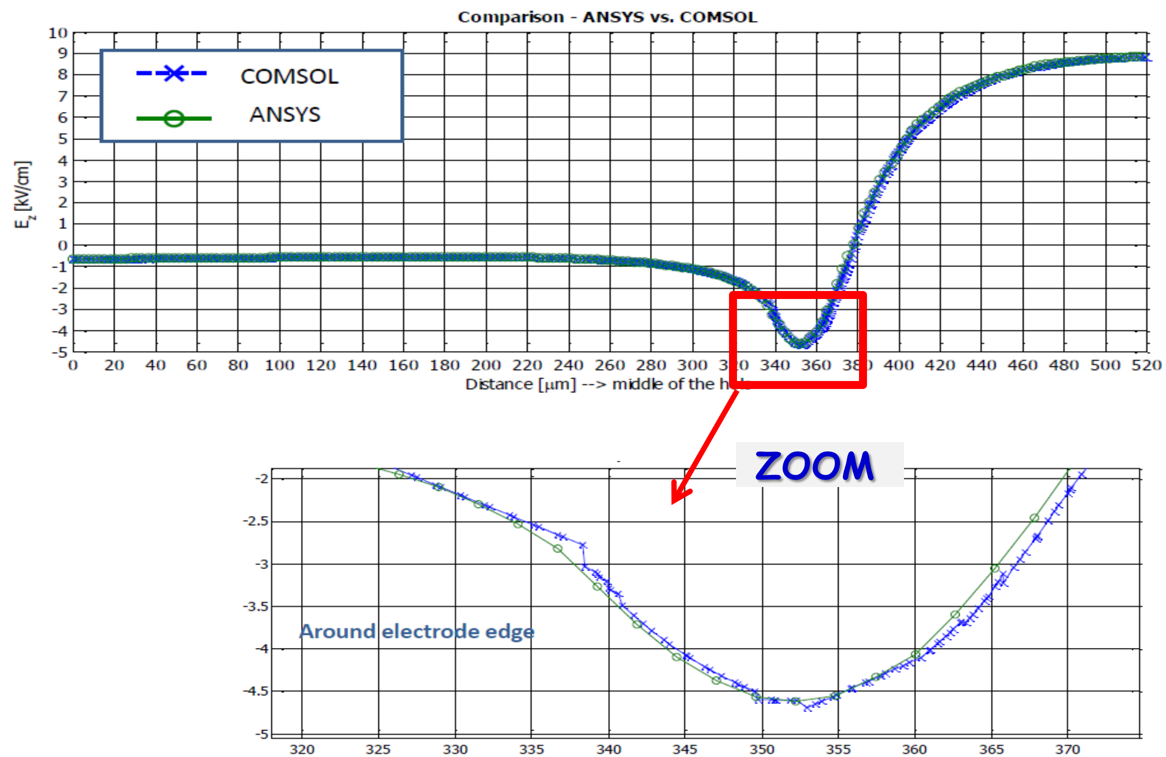
- **Calculation of ELECTROSTATIC CONFIGURATIONS**
  - **Commercial tools, operation not trivial**

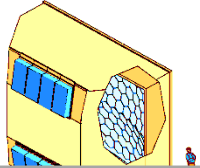
Comparative study using Ansys® and Comsol® after fixing some bugs (by us) now satisfactory agreement



Test Line – in median direction (0.0001 um above the surface)



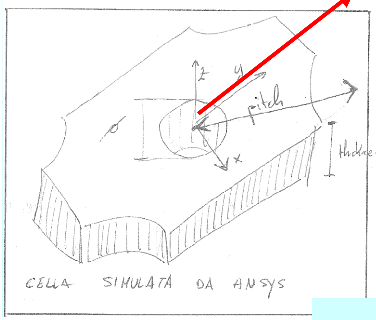




THE ISSUE 2/2

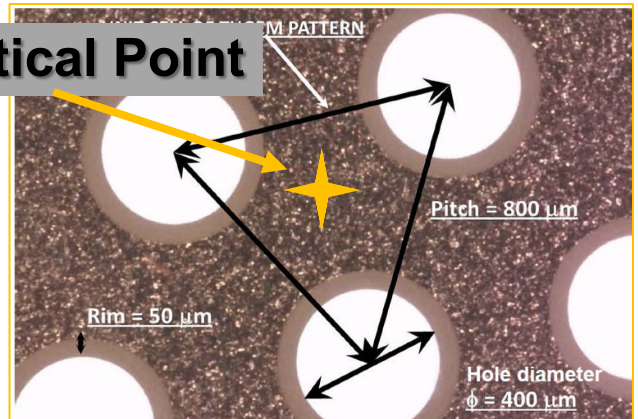
No drift field consider here, approaches by electrostatic calculations

Basic cell structure



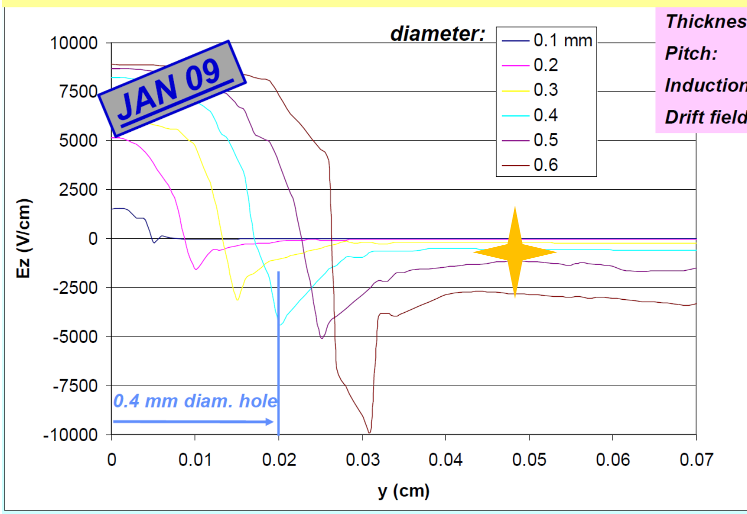
DIPOLE FIELD

Critical Point



ΔV: 1500 V

Values of E_z along the "y" axis, for different diameters



More about E at critical point

Only 2 relevant parameters:
1. Active surface
2. thickness

Thickness scan

(ΔV = 1500V)

Electrostatic calculations using COMSOL